Diffusion of solar water heating technology in Tanzania : opportunities and constraints

van Campen, B.M.J.

Award date:
1996

Diffusion of solar water heating technology in Tanzania

Opportunities and constraints

Bart van Campen

May 1996

Graduation research for International Technological Development Sciences
Supervisors:

Dr. A.M.C. Lemmens	Faculty of Technology Management, International Development Sciences, EUT
Dr.Ir. M.H. de Wit	Faculty of Building & Architecture, Building Physics, EUT
Drs. H. Gaillard	Faculty of Technology Management, International Development Sciences, EUT
R. Nindie	Tanzania Industrial Research and Development Organisation

Faculty of Technology Management
Eindhoven University of Technology (EUT)
P.O.Box 513
5600 MB Eindhoven
The Netherlands

Preface

This report is the result of work carried out as part of the MSc program in International Technological Development Sciences (ITDS) at the Eindhoven University of Technology (EUT), The Netherlands. The program aims at training engineers for a professional career in the field of development issues. The focus of the program is on technology development, transfer and industrialisation in particular. Students are educated in one of the technical disciplines of their own choice as well as in social sciences in order to be able to analyze the relationship between technology, technological development and the impact on society. In the final year a research in this field has to be set-up and executed in a developing country. This way the student acquires his or her first research experience as well as living and working in a developing country for an extended period of time (generally six months).

In 1987 I studied Electrical Engineering at the Technical University in Delft. Not satisfied with the program I decided to change studies to Public Administration at the Erasmus University Rotterdam, where I graduated in 1993, specializing in development administration and international organisations. By then I found out that my technical roots were calling me back and that the MSc program in ITDS offered the possibility of integrating my interest in both technical, socio-economic and administrative aspects of development issues. In 1993 I took up this challenge, specializing in renewable energy technologies, notably solar systems.

At the end of 1994 a request from the Tanzania Industrial Research and Development Organisation (TIRDO) reached the EUT, for a student to do research on the diffusion of thermal solar systems in Tanzania. In March 1995 I left for Tanzania, where I stayed and gathered research information until November 1995. Apart from executing the research - which also took me to Kenya - I took the chance of exploring the enormous and beautiful country that Tanzania is.

Of course the process of doing research and writing a report is not always delightful and in those moments the support of other people becomes even more important than normal. Therefore, I would like to thank everybody that supported me in this research effort, but especially:

- Dr. Lex Lemmens, Dr.Ir. Martin de Wit and Drs. Herman Gaillard, the supervisors for my research. I thank them for their patience, guidance and encouragements;
- Frank van der Vleuten and Annelies Balkema for their useful comments and suggestions while executing the research in Tanzania, but also for their company and the moments of relaxation in the evenings while the food cooked on the 'jiko bora';
- my family and friends for their patience and support through the trials and turbulations of producing a research report;
- Bart and Cis Deus of BACIBO; Bart van der Ree and Huib Visser of TNO for providing me with valuable information on solar water heaters in general and in Tanzania in particular;
- Dr. Geoffrey John of the University of Dar es Salaam; Justin Tarimo, Robert Nindie, Daniel Makundi, Dr. G.J. Njau and the other TIRDO staff members that helped me to assimilate to Tanzanian circumstances and made hard moments lighter with a joke, a beer or other diversions.
- The Professor Gelissen Foundation, Arnhem, The Netherlands and the WSO Fund (Wetenschapsreizen Studenten Ontwikkelingslanden), Eindhoven, The Netherlands for their more than generous financial contributions to my research.

Abbreviations

AISCO	Agricultural and Industrial Supplies Company Ltd.
BoS	Bureau of Statistics
CAMARTEC	Centre for Agricultural Mechanisation and Rural Technology
COMESA	Common Market for Eastern and Southern Africa
COSTECH	Tanzania Commission for Science and Technology
DANIDA	Danish International Development Agency
EAC	East African Community
EIU	Economic Intelligence Unit
ESMAP	Energy Sector Management Assistance Programme
EUT	Eindhoven University of Technology
GDP	Gross Domestic Product
GTZ	Gemeinschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)
IMF	International Monetary Fund
ISO	International Organisation for Standardization
ITDS	International Technological Development Sciences
MSc	Master of Science
MWEM	Ministry of Water, Energy and Minerals
NGO	non-governmental organisation
PBP	(simple) pay-back period
PTA	Preferential Trade Area
PV	photovoltaic
R&D	research and development
RET	Renewable Energy Technology
SADC	Southern African Development Community
SEP	Special Energy Programme
SWH	solar water heater
TBS	Tanzania Bureau of Standards
TANESCO	Tanzania Electric Supply Company Ltd.
TATEDO	Tanzania Traditional Energy Development Organisation
TIRDO	Tanzania Industrial Research and Development Organisation
TNO	Netherlands Organization for Applied Scientific Research
TPDC	Tanzania Petroleum Development Company
TROSS	Tropical Solar Systems
UDSM	University of Dar es Salaam
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USAID	United States Agency for International Development
VAT	Value Added Tax
WB	World Bank

List of figures and tables

Table of contents

Chapter 4 Research framework

Chapter 5 Solar water heating in Tanzania

Chapter 6 Promoting the diffusion of solar water heaters in Tanzania

Appendices

Chapter 1 Introduction

1.1. Background and justification

This report is based on research in Tanzania and Kenya as part of the MSc programme in International Technological Development Sciences at the Eindhoven University of Technology, The Netherlands. To acquire the MSc title the student is required to do a research in a developing country on the role, use and/or production of technology in developing countries and write a thesis on this subject. This gives the student a possibility to gather his or her first experience in setting up and performing such a research.

At the end of 1994 a request from the Tanzania Industrial Research and Development Organisation (TIRDO), Dar es Salaam, Tanzania, reached the Eindhoven University of Technology for a student to do research on the diffusion of thermal solar systems in Tanzania, with an emphasis on local production and the possible role of TIRDO. With a personal interest in the use of renewable energy systems in developing countries and solar systems in particular, I decided to take up this research. Between April and October 1995 I was in Tanzania to gather information. Analysis and compiling the report took up to May 1996.

The practical relevance of the research lies in the information gathered on the use of these solar systems in Tanzania and the resulting recommendations for stimulation of use and local production. The scientific relevance is based on the use of different theories on innovation diffusion to develop a framework for the diffusion process. Many diffusion studies have been done in various fields, but often without much interchange of experience or methodology. Furthermore little theoretically based research has been done on the diffusion of renewable energy systems and solar systems in particular. Important elements of the different diffusion theories are put together in a system framework in order to study the interaction between elements of the system and the environment. This framework is used to describe and categorize the opportunities and constraints for the use and production of solar systems in the case of Tanzania and identify possibilities to promote the diffusion. The framework could also be used for other countries to facilitate case comparison. This is proven with a case in Kenya.

1.2. Objectives and general research question

Research question:
What are the opportunities and constraints for the diffusion and local production of solar water heaters in Tanzania? What role could TIRDO play in the diffusion process?

The original objectives of the research were to:

1. make up an inventory of present use of solar water heaters in Tanzania, including the relevant existing infrastructure and policies;
2. assess opportunities and constraints for application of solar water heaters;
3. assess opportunities and constraints for local production of solar water heaters in Tanzania;
4. identify options for TIRDO and other relevant institutions to stimulate the diffusion and local production of solar water heaters in Tanzania;
5. systematically bring together the information, accessible to interested parties;

During the research it became clear that in principle local production of solar water heaters was very well possible in Tanzania and even practised sporadically, but that little demand for these products existed yet. The focus of the research therefore became the opportunities and constraints for application (2) and possibilities for stimulation (3). To be able to gather more information, learn from experience and make a case comparison possible, an additional (pre-)study was done in Kenya.

1.3. Methodology

The main research questions are of a qualitative nature: <u>How</u> are solar water heaters diffused in Tanzania and what factors play a critical role? And <u>how</u> can the diffusion process be influenced or stimulated. The research is therefore mainly of an exploratory, descriptive nature, using qualitative research methods. Exploratory, qualitative research mainly occupies itself with the <u>nature</u> of social events; in contrast with quantitative research that occupies itself with the <u>extent</u> of elements of social events occurring, while the nature of these events is accepted as more or less given (Maso, 1987). Qualitative approaches require a rather open set-up of research in which large amounts of information have to be gathered and processed without the use of a prior model or hypotheses on the social events studied. To be able to give some structure to this research, a framework is developed on the basis of relevant literature on diffusion theories. The framework is used to describe and categorize opportunities and constraints in the diffusion of solar thermal systems in Tanzania. Data for the research is gathered using the following sources:
- secondary literature;
- semi-structured interviews with resource persons;
- semi-structured interviews with (representatives of) relevant institutions, users, distributors, etc;
- inspection of solar water heating systems;
- micro-economic analysis of solar water heaters and competing technologies;
- case comparison with Kenya;

The original question regarded the use and production of solar thermal systems in Tanzania, but due to limitations in time and research funds, choices had to be made in the following areas:

1. Of all solar thermal technologies, the solar water heating technology was chosen, because of its simplicity in principle, design and production; the proven maturity of this technology and its market in other countries[1]; and therefore the possibilities of widespread use and production in Tanzania and neighbouring countries;
2. The geographical area was restricted mainly to the urban areas of Dar es Salaam, Arusha and Mbeya in Tanzania and Nairobi in Kenya;
3. A selection had to be made of organizations to be visited and representatives interviewed; in the field of distribution and production all the companies identified in Tanzania were visited and a selection in Kenya; of the institutions the main educational, research and policy institutions were visited, including the most important donor organisations in Tanzania and the electricity company; of the (possible) users a selection was made within the household and commercial sector;
4. A limited number of factors were studied; these will be discussed in more detail in chapter 4.

1.4. Structure of the report

In chapter 2 different theories on diffusion of innovations are discussed and compared. The diffusion process is also studied in the light of the larger innovation-development process, with special emphasis on the role of R&D. These insights are used in the development of the research framework and questions.

Chapter 3 describes the principles of solar water heaters, different technical variations and important aspects of installation, maintenance and repair. The chapter ends with an evaluation of the economics of solar water heating as compared to competing technologies.

Chapter 4 contains the research framework based on chapters 2 and 3. Also prior experiences in research on the diffusion of solar water heaters are highlighted. The framework developed is used to do a quick pre-study on the diffusion of solar water heaters in Kenya.

In chapter 5 the diffusion system of solar water heaters in Tanzania is described using the framework from chapter 4 and the lessons learned from the case of Kenya.

Chapter 6 then finalises with a summary of opportunities and constraints for the diffusion of solar water heaters in Tanzania and options and recommendations for the stimulation of the diffusion process with particular attention to the possible role of TIRDO.

---

[1] especially in countries like USA, Australia, Greece, Israël.

Chapter 2 Theoretical framework

2.1. Theories on diffusion of innovations

2.1.1. Introduction

The introduction of a new idea, product or concept often meets with opposition, even if the advantages seem to be obvious. Some introductions, however, progress smoother than others. Why? What conditions or factors determine success or failure of diffusion?

Already at the beginning of this century, anthropologists were studying the introduction and diffusion of new ideas and technologies. The rise in diffusion research, however, came in the 1940s in the USA, notably after the Ryen and Gross (1943) published their study into the diffusion of hybrid maize seeds under farmers in Iowa state. Their methodology influenced much of the later diffusion research. Diffusion research spread to Europe and to a variety of fields, particularly: agriculture, education, medical sociology, marketing, geography and rural sociology. Each of these disciplines pursued their research in its own specialised way without much interchange with other disciplines, until the boundaries between the traditions began to breakdown in the 1960s. By then diffusion research was also extended to developing countries, especially in the fields of rural sociology, health and family planning. In the 1970s more and more criticism arose on the traditional demand-side oriented approach to diffusion research and alternative approaches were attempted. More attention was given to the socioeconomic context of diffusion and the goals and necessity of innovation diffusion itself. Two main 'schools' of diffusion research can be recognised: a demand-side and a supply-side oriented approach; these will be described in paragraph 2.1.2. and 2.1.3. respectively. Before describing these theories, however, a few concepts will have to be defined.

Diffusion research has its roots in communication sciences and therefore widely makes use of the concepts information and uncertainty. **Uncertainty** is the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probabilities of these alternatives. This motivates an individual or other unit to seek information. **Information** therefore affects the uncertainty in a situation where a choice exists among a set of alternatives. Information comprises all the messages in a communication process that the participants in the process (sender and receiver) ascribe meaning to. Information can be cognitive (knowledge, ideas, theories, etc.) or emotive (fear, sadness, superiority, etc.) or volitional (goal-oriented, display of power). The messages can be objective or subjective (containing value judgments, persuasive elements, etc.). Information about an innovation can be about the technology itself: How and why does the technology work? And it can be about the impact of the innovation. This type of information generally contains more subjective elements.

'**Diffusion** is the process by which an innovation is communicated through certain channels over time among the members of a social system.'
Diffusion is a special kind of communication in that the 'messages' communicated are concerned with new ideas, where communication is a process in which participants create and share information with one another in order to reach a mutual understanding. Communication contains a message (information), a receiver (potential adopter) and a sender (a diffusion or change agency). The concept **dissemination** then is often used for managed and directed diffusion. Since the line between directed and undirected diffusion is vague, in this report the term diffusion is used consistently, which can both mean directed and undirected processes.

An **innovation** is an idea, product, technique or practice that is perceived as new by an individual or another unit of adoption. This 'newness' is relative: a colour television or bicycle might be perceived as new - i.e. an innovation - in a Third World nation, while it is not in Western Europe. An innovation presents the potential adopter with a new alternative or alternatives, with new means of solving problems. The chances of the new alternatives being superior to the previous practice are not exactly known by the adopter. Therefore an innovation introduces uncertainty and its adoption poses a risk. The adopter is motivated to seek (new) information. In this research (and in the majority of diffusion research) the innovation is a **technology**, which Walubengo defines as 'objects, techniques and processes which facilitate human activity in terms of: first, reducing human energy expenditure, second, reducing labour time, third, improving spatial mobility and fourth, alleviating material uncertainty.'[2]

Communication **channels** are the means by which messages (information) get from one individual (or unit of adoption) to another. The receiver should be the potential adopter, the message information on the innovation, while the sender is the diffusion agency. Different types of communication channels exist: mass media channels, professional diffusion agent contacts, demonstration activities, and interpersonal channels between peers. From a more infrastructural point of view ('supply-side' approach) channels are also physical distribution channels.

Time is a basic concept that escapes definition. The element time is an important variable in the diffusion of innovations as the diffusion process involves the change over time of adopters' attitudes towards innovations and adoption-decisions. Often the diffusion pattern of an innovation can also be described over a target group or a geographical area. Finally, innovation diffusion can involve changes over time in the social system, institutions and organisations involved.

---

2 Bryceson, quoted in Walubengo, 1993. A crude definition of a certain technology by Langrish (1972, in Rosenberg, 1982) is: 'a body of knowledge or industrial practise ... sufficiently developed to provide a university degree at MSc or final BSc level.'

Broadly speaking a **social system** is a complex in which a set of interrelated units find their function as part of this complex. Systems do not exist as such, but are used as a model of reality. The essence of a social system is that the units that make up the system are subject to this system. The system itself is also influenced by its environment, i.e. every unit outside its boundaries. The system can be a nation, a village or an organisation. The units can be individuals, groups, organisations or other subsystems. Diffusion occurs within the boundaries of the defined system. The system has a structure, i.e. a patterned arrangement of the units. This structure gives stability and regularity to the system. This structure determines the social relations between the units (social structure), but also the information flows (communicative structure). A social system also has norms, which are the established behaviour patterns for the members of a social system. They define a range of tolerable behaviour and serve as a guide or standard for the members of the social system.

Another way of looking at diffusion of innovations is as a process of social change, in which the introduction and diffusion of an innovation is part of a process of change in the structure and function of a diffusion system. A **diffusion system**, then, is also a type of social system. It encompasses both senders and receivers of the innovation communication. It also encompasses the channels through which the innovations are communicated and the organisations and means used in this process. These units - senders, receivers and channels - are interrelated, influence each other. Together they form a system with a certain structure, that can be delineated from its environment. Elements of the environment can influence the system too, however. Both the diffusion system and its environment evolve over time as the innovation changes. This perspective draws more attention to the social and institutional context of innovation diffusion and fits the 'supply-side' school of innovation diffusion research. The communication perspective fits the 'demands-side' school best.

2.1.2. Demand-side or adoption approach

Most of the diffusion research has focused on the demand side in which research efforts are focused at the (possible) adoption of a certain innovation by potential users. The adoption of an innovation is primarily seen as the outcome of a communications process. A fundamental step in this research is the identification of factors influencing the flow of information and the influence of information on resistances to adoption. Important aspects of this resistance are the individual's attitude towards innovation and the congruence of an innovation with the individual's socio-economic and psychological characteristics. The innovation itself, its source and its availability are considered as more or less given and not part of the area of study.

In a literature survey Rogers and Shoemaker (in Rogers, 1995) found that 2/3 of more than 6000 hypotheses on diffusion involved **individual innovativeness** and **rate of adoption. Individual innovativeness** is the degree to which an individual (or other unit of adoption) is relatively earlier in adoption than others. Much research has been done on categorisation of potential adopters in categories of innovativeness[3] and establishing socio-economic characteristics of these categories. Early adopters are often found to have a higher socio-economic status, higher education, more social contacts, etc. Other research has focused on the relation between important characteristics of innovations as perceived by potential adopters and the **rate of adoption**, being the relative speed of acceptance of an adoption:

1. relative advantage: the degree to which an innovation is perceived as better than the idea/situation it supersedes; this can be on an economic, social-prestige, convenience or other scale. The objective advantages are less important, since research has shown that most innovation decisions are based on perceived advantage. Relative advantage is positively related with the rate of adoption;
2. compatibility: degree to which an innovation is perceived as being consistent with existing values, needs and past experiences of potential adopters and not conflicting with the norms of the social system. In general it can be said that an innovation is more easily adopted if the necessity is smaller for the adopter to change important aspects of his behaviour. In other words: compatibility is positively related with the rate of adoption;
3. complexity: degree to which an innovation is perceived as difficult to understand and use by most members of a target group or social system. Complexity is negatively related with the rate of adoption;
4. trialability: degree to which an innovation may be experimented with on a limited basis. Trialability is positively related with the rate of adoption;
5. observability: degree to which the results of an innovation are visible to others. Observability promotes discussion on innovations and possible persuasion and is therefore positively related with the rate of adoption;

Strategies and communication channels to influence the adoption decision have also been studied from the adopters point of view. Decisions to adopt an innovation often

[3] often categorised according to: innovators-early adopters-early majority-late majority-laggards

turn out to be based on 'subjective' persuasion elements instead of 'objective' evaluation of advantages and disadvantages based on scientific information. Interpersonal channels are better at communicating these persuasive elements and therefore important in influencing the final decision on adoption. Mass media are more efficient in transferring awareness knowledge to a wide audience. Such research has also studied important characteristics of diffusion agencies, as innovation channels. Based on numerous studies, Rogers suggests that a diffusion agency's relative success in securing adoption of an innovation by its clients is positively related to: client orientation; the credibility of agencies in the eyes of the target group; and the ability of the diffusion agency to diagnose clients' problems and establish a continuous relationship.

The adoption school of diffusion research has added immensely to create insight into the process between introduction, and widespread adoption of innovations and results have been used to make diffusion efforts more effective. Therefore it has won a prominent place among others in the fields of communication, public relations, marketing and rural sociology. It also has some major shortcomings, however, that can not be left unmentioned.

One important criticism involves the focus on the individual level without adequate attention to structural elements. The social system and structure are only studied in as far as they influence the individual's adoption decision. By concentrating research on the adoption decision of individuals and barriers at this level, the problems and solutions will also be found at this level. The tendency is to find blame with the individual (non-adopter) for not being innovative enough, for not being rational and accepting the advantages of the innovation, instead of looking at barriers in the diffusion system. These criticisms draw attention to the decision structures and institutions on what innovations to diffuse, to whom and on what criteria these decisions are based on. These decisions involve the supply of innovations.

In 1973 a report was published[4] on a research in 10 Latin American countries into the causes for stagnation in the development of the agricultural sector. These studies pointed at institutional factors - notably land tenure and control - as the most important factors in agricultural development ánd the diffusion of innovations. A wave of literature followed criticizing the generalizability of existing innovation diffusion theory, notably involving the introduction of the 'green revolution' in agriculture. Much of this criticism took the form of 'dependencia' and imperialist theories criticizing not only the focus on the individual, but also the modernization paradigm that is at the basis of much diffusion research. Such research is loaded with a pro-innovation bias: innovation is necessary and an innovation should be diffused and adopted by all members of a social system. Because of this pro-innovation bias diffusion agencies are generally focusing on 'progressive' clients (adopters), who are generally the individuals with a higher socio-economic status. These will acquire most benefits from the innovation, thereby increasing the socio-economic gap. These criticisms therefore involve the necessity and consequences of innovations

---

[4] S. Barraclough (ed.); Agrarian structure in Latin America; Lexington, Massachussets, 1973; in Hardeman (1984).

2.1.3. Supply-side or infrastructural and market approach

As a reaction to the dominance of the demand-side approach, several researchers have focused more on the supply-side of innovation diffusion. Brown (1981) is the most important component of this school. He argues that the demand-side approach implicitly assumes that all have an equal opportunity to adopt and focuses, therefore, upon individual characteristics to explain differences in the actual terms of adoption. He claims that these equal opportunities do not exist and is interested in the factors shaping these opportunities. He puts emphasis on the role of institutions and organisations that diffuse innovations and on barriers in the diffusion system and its environment:
[..] that individual behaviour does not represent free will so much as choice within a constraint set and that it is government and private institutions which establish and control the constraints. As such they play a major role in shaping diffusion patterns'
(Brown, 1981)

Brown stems from a geography tradition of diffusion research, in which the role of spatial distance in diffusion is an important focus. The existence of a distribution infrastructure and the distance between a distribution point and a potential adopter determine the effective availability of an innovation. Many studies have shown a clear relationship between the distance to a distribution point for an innovation and the level of adoption, i.e. the percentage of clients in an area that have adopted an innovation. Brown describes the example of a milk powder factory in Aguascalientes, Mexico. Only after Nestlé built the factory, set-up a transport infrastructure and stimulated local farmers to take cows and sell milk, the area could become a - commercially - successful dairy area. Garst (1972 in Brown, 1981) in a study on the diffusion of agricultural innovations in Kenya, also notes a strong correlation between diffusion patterns and the location of distribution and production infrastructure.

By extending the 'availability' to social, economic and organisational aspects, he comes at the concept of accessibility. Before individuals can make a decision to adopt or not adopt an innovation, it first has to be available. Furthermore they have to know of its existence and able to buy the innovation. This accessibility depends a lot on the strategy of the diffusion agency involving target group, price, credit arrangements, promotional activities, etc.

The availability and accessibility of the innovations limit the geographical area for adoption of innovations; only when these have been secured in a certain area, demand-side factors can influence the diffusion process. Availability and accessibility are in large part determined by diffusion agencies in two stages:

1. the establishment of diffusion agencies: the diffusion system;
2. the implementation of a diffusion strategy;

The establishment of diffusion agencies: the diffusion system

Through the establishment of diffusion agencies an innovation is made available to potential adopters; hence the location, timing and order of their establishment sets the broad outlines of the diffusion pattern. There are several processes of diffusion agency establishment, which can be put on a continuum between 'diffusion under a centralised decision-making structure' (centralised diffusion system) and 'diffusion under a decentralised decision-making structure' (decentralised system). In between these poles are a series of diffusion processes 'under a decentralised decision-making structure with a coordinating propagator' (coordinated system).

In a centralised system decisions a single unit, organisation or individual determines the innovation to be diffused, the number of diffusion agencies to be established, including their size, location and strategy. The decision-maker might be a government body or a private firm. In the case of a private firm, ideally, markets would be ranked according to their profitability and exploited in order of declining profitability. The critical factors in this process are capital, sales potential, logistics and elasticity of the agency's profitability with regard to sales. In the case of a government agency, more political factors - like development priorities for certain sectors or regions and considerations of equity - will generally play a role in these decisions. Many governments of developing countries in the 1970s, for instance, started large agricultural extension programs for the diffusion of innovations to increase agricultural productivity. These programs were very hierarchically structured and controlled by central government. Still, ideally, decisions should be made on the basis of cost-benefit analysis. In many third world countries information to base such decisions on is often not available. Brown analyses that markets under such conditions system often develop geographically along a web-like diffusion pattern, i.e. markets close to an already existing market develop faster; rather than a hierarchical exploitation of the most profitable markets. This emphasizes the important influence existing infrastructure has on future developments.

In an extremely decentralised system, there may not be any diffusion agency involved and the diffusion is completely self-managed by (potential) adopters. Here, horizontal networks among the clients are the main mechanism through which innovations spread; this might for instance be the case for an agricultural improvement invented by a farmer, that spreads through a peer network. Under a less decentralised decision-making structure each diffusion agency is established independently, often by an entrepreneur. Each entrepreneur will have to make decisions on the basis of capital availability, expected profitability, competition, etc. Characteristics of the entrepreneurs are important in this type of diffusion: technical, promotional and management skills, congruence between innovation and ongoing activities of the entrepreneur. Thus, those places with human resources capable of being aware of and exploiting the innovation are more likely to have diffusion agencies established.

In a coordinated system some elements of the diffusion process, such as information flow or incentives for agency establishment, are controlled or coordinated by one body. The diffusion pattern is therefore influenced, but not determined by this body. One thing in particular that can not be controlled is the decision to establish a diffusion agency. In general factors in the environment can have a large influence on decisions of diffusion agencies. In a coordinated system such factors are manipulated deliberately by a coordinating body in order to create an 'enabling environment' for the diffusion of specific innovations (see paragraph 2.2.4.).

There are advantages and disadvantages to the use of centralised or decentralised systems of diffusion[5]. In decentralised systems innovations are more likely to fit with users' (adopters') needs and problems, because the 'distance' between decision makers and users is smaller. In a completely decentralised system the users make all decisions concerning the innovation themselves. Shorter distances in lines of decision and less coordination problems, can make such decentralised structures more effective. Experience shows for instance that in a participatory set-up of innovation diffusion projects, users are closely involved in prioritizing and decision making; this will add both to the adaptation of the innovation to local circumstances and to a sense of control by users and, hence, more support. Decentralised structures might also lead to problems, depending upon the type of innovation. In a decentralised system it might be difficult to maintain technical expertise and infrastructure. Also, low quality imitations of a successful innovation might be diffused because of lack of quality control, possibly damaging the market for these innovations. These problems will arise least when adopters themselves have much of the (technical) expertise in the field: this is for instance the case with many agricultural innovations. Furthermore, lack of coordination or oversight will hamper the spread of information and lead to the waste of efforts and resources. Finally, difficulties will arise in diffusing innovations that are not popular with individuals but deemed necessary from a collective (governmental) perspective e.g. environmental conservation measures.

In general, research from the supply-side perspective has shown that in many cases of diffusion existing customs, organisations and networks are used from the top down, instead of bottom up as the demand-side approach would suggest. This emphasizes the importance and influence of existing infrastructure, market and institutions on the diffusion of innovations.

[5] Note that there will not always be a choice whether to opt for a centralised or decentralised system of diffusion. This will also be determined by socio-economic factors and existing institutional environment.

Diffusion strategy

The strategies of diffusion agencies create different levels of access to the innovation depending upon a potential adopter's economic, social and locational characteristics and thus add to the constraints within which adoption occurs. Four elements of the agencies' diffusion strategy are important:

1. the development of infrastructure and organisational capabilities
2 pricing policy
3 promotional communications
4 market segmentation and selection

The first two elements primarily affect the objective attributes of the innovation, while the latter two primarily affect the more subjective attributes of innovations, i.e. the beliefs of potential adopters about the objective attributes and their evaluation. The influence of the different elements on diffusion patterns will be discussed, including the interaction between the elements.

In order for the agency to choose its strategy it will have to know a lot about the social, economical, psychological and locational characteristics of the potential adopters. Also the influence of the potential adopters' social network is important to know. Clearly elements of the demand-side approach come into the picture. To gather enough information to choose a diffusion strategy, often marketing studies are done on potential adopters, using demand-side approaches. Furthermore it is important to know the influence of existing infrastructure and environment, because the actions of other institutions in both public and private sectors also interact with and affect both diffusion agency establishment and strategy. Among others these institutions provide various public infrastructures such as (tele)communication, transportation, water and energy infrastructure as well as other incentives and disincentives to adoption. Furthermore general economic conditions set boundaries to markets for innovations and competition by other organisations or technologies influences the division of these markets. Fig. 2.1. summarizes these aspects.

Development of **infrastructure and organisational capabilities** is one means of enabling and enhancing diffusion of an innovation. In the example described on page 9, Nestlé promoted the diffusion of commercial dairy farming by the set-up of a milk collection system. In other cases an agency might choose not to set up its own infrastructure, but utilize existing infrastructure. Use of public infrastructure such as roads, water and electricity will probably be necessary. Organisational capabilities might also include human resource development to generate enough expertise to manage, control, install and service the innovation diffusion. Some agencies have their own training facilities, others hire people educated at public schools or universities. Some innovations, however, are more 'infrastructure-dependent' or constrained than others. In the case of electrical appliances, the dependency on electricity infrastructure is clear. Mobile telephones, however, are much less dependent on infrastructure than their wired cousins, giving them a clear advantage in countries where the existing telecommunications infrastructure is weak. Often a dependency also exists on installation, maintenance and servicing infrastructure.

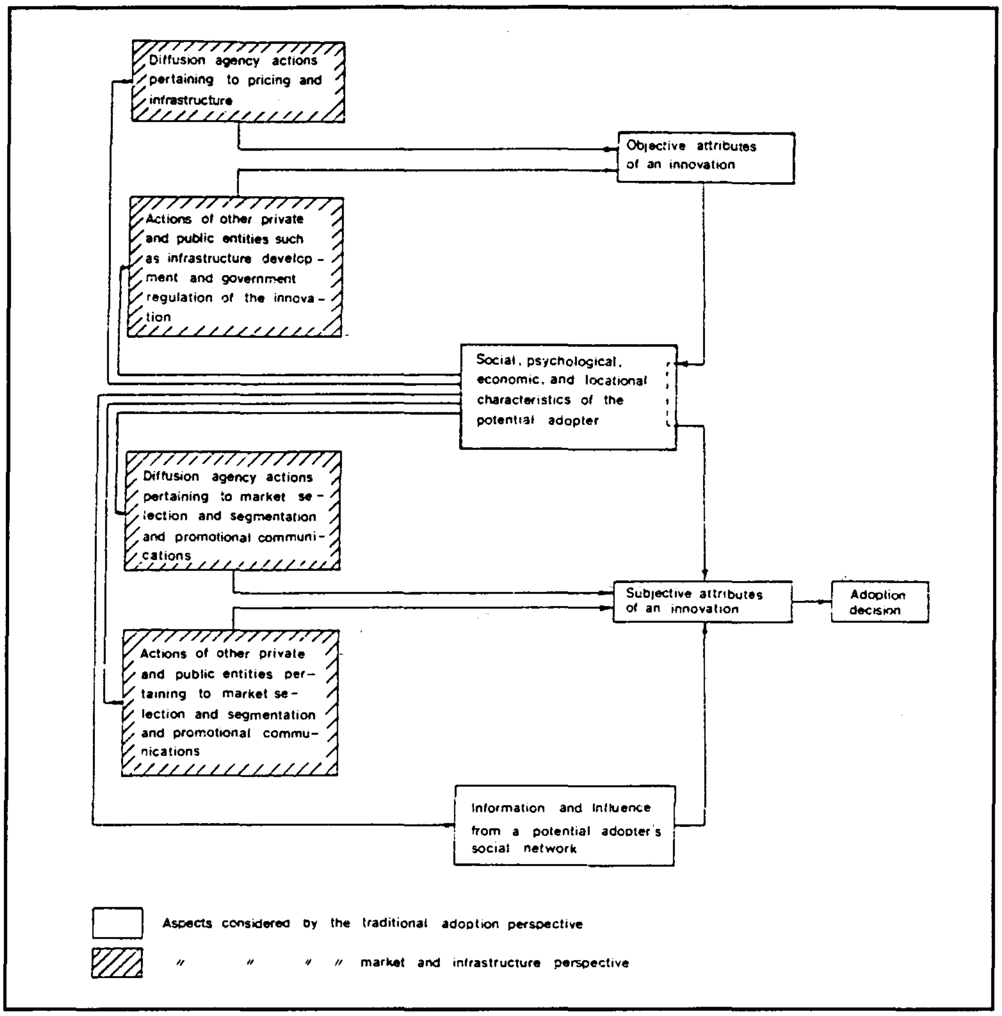


Fig 2.1. The influence of diffusion agency action and environment on adoption behaviour (source: Brown, 1981).

A television is in a much higher price category than a tomato, limiting the range of customers. Within these broad price categories, however, agencies have considerable discretion in their **pricing policies.** A private company will probably set its prices to maximize profits, while a public agency might seek to minimize costs for its clients. For tactical reasons, prices might be altered, however, for instance to enhance market penetration or share. In general, prices reflect - apart from production costs - the costs of infrastructure and promotional communications. An agency might want to choose to set market- and/or distance related prices. Prices for innovations are often an important factor in the adoption decision, either through mere financial capacity: being able to afford the investment - a particular important aspect limiting markets for innovations in a developing context; or through competition with alternative technologies or products. Prices or investment costs are not the only economic factor involved however. In many cases the (annual) costs - consisting of investment as well as fuel, operation and maintenance costs - are even more important. This also involves evaluating such factors as economic life-time and capital costs. Finally, it has been shown that in the end people generally do not decide on the basis of objective advantages and disadvantages, but on their perception of these advantages. This might also include 'objective' cost comparison, but also other elements more to do with image. Diffusion agencies can try to influence the perception of their innovations.

A diffusion agency will generally try to **promote** the adoption of its innovation by **communication** of information about the innovation and its characteristics. The choice of channel has a large influence on the effectiveness and range of communication. As mentioned before, personal channels are more effective at transmitting complex information and at changing people's attitudes (mouth-to-mouth promotion). Mass media channels reach a larger number of people over a larger area. The choice of media influences the audience reached: the audience of a local newspaper will be different from the one of national television, but so will the price for communication. With different media, different socio-economic groups will be reached. In many Third World countries mass media channels are less developed and people - especially in rural areas - rely more on interpersonal communications. Finally, information from some sources might be promotional or counter-promotional; government campaigns might support the sale of efficient electric appliances marketed by private entrepreneurs; bad experiences with a (similar) innovation can have a ruining effect on its image and credibility and hamper its future diffusion, however.

A diffusion agency might - implicitly or explicitly - vary its infrastructure, pricing policy and promotional communications to particular **market segments**, that are deemed more profitable or in other ways more advantageous to the agency. An example of implicit market segmentation is the 'two-step flow model' of communication that is often used in government agency diffusion efforts. Initially the more innovative elements of a target group are approached directly. These are then expected to promote the innovation further to less innovative members through personal contacts. In practise the results might not differ a lot from a market approach in which the most profitable segments of the market are targeted first.

2.2. Diffusion as part of a larger process

2.2.1. The innovation-development process

In paragraph 2.1.3. the influence of supply-side factors on diffusion and adoption of innovations was described. Still, in the supply-side approach the innovation itself is hardly regarded and the source of innovations is scarcely considered. Where do innovations originate and what influence does this have on the further process? Furthermore the consequences of innovation adoption are hardly considered. To study these aspects it will be beneficial to view innovation diffusion in the wider perspective of an innovation-development process. Though Rogers is an exponent of the demand-side approach, he has reflected on such a process and described it in 6 phases:

1. Perceived problem or need. Such a problem or need can rise from a practical situation or from a diffusion or R&D agency.
2. Research. The knowledge base for a technology usually derives from basic research, defined as 'original investigations for the advancement of scientific knowledge that do not have the specific objective of applying this knowledge to practical problems. Applied research - in contrast - consists of scientific investigations that are intended to solve practical problems.
3. Development of an innovation is the process of putting a new idea in a form that is expected to meet the needs of an audience of potential adopters. Innovation development is always based on research, but it is not always clear where to draw the line between (applied) research and development. They are therefor often mentioned in one phase: research and development (R&D).
4. Commercialisation. A developed innovation has to be packaged in such a form to be ready for adoption by users, involving production, manufacturing, packaging, marketing and distribution. Often private firms take up this phase and it is therefore called commercialisation. This is the phase that Brown c.s. mainly refer to in their supply-side studies (see 2.1.2.).
5. Diffusion and adoption: the actual process of reaching and persuading (potential) adopters of innovations. The main part of diffusion research is focused at this phase (see 2.1.1.).
6. Impacts: has adoption of the innovation led to the solution of the original problem? What are the (un)intended and (un)desired consequences?

It is important to remark that these phases are a model of the actual process: in reality not all phases will always occur in linear sequence: in many cases certain phases do not occur at all or the time-order is changed. The interest of this exercise is to study the links between the phases and particularly the influence of the first three phases on the diffusion process (phase 4 and 5). Brown summarizes the first three phases under the concept 'inventive activities'. These will be described in paragraph 2.2.2. In paragraph 2.2.3. the goals and impacts of innovation development and diffusion are discussed in more detail. Finally the influence of the institutional environment and the possible government instruments to influence the diffusion process will be discussed in paragraph 2.2.4.;

2.2.2. Source of innovations: inventive activities

Fig 2.2. shows the innovation-development process schematically. Inventive activities encompass the transformation of an idea into a marketable product or service (innovation). The initial idea or design arises from a fusion of technical feasibility with the recognition of a need or demand. In subsequent R&D activities a possible solution (invention) is found. Through prototyping this solution is tested into practise and, if successful, transferred to a diffusion agency and made ready for diffusion. This view on the innovation process could be viewed as a demand-side approach of R&D activities. From a supply-side perspective important questions are how a need or demand is recognized, by whom and who decides on which problems are picked up for subsequent R&D activities? In other words: what is the influence of institutions on the direction of R&D activities? It should also be noted that an innovation is generally not finished after the first diffusion activities: through feedback from practical applications and continuous improvement, an innovation will develop further.

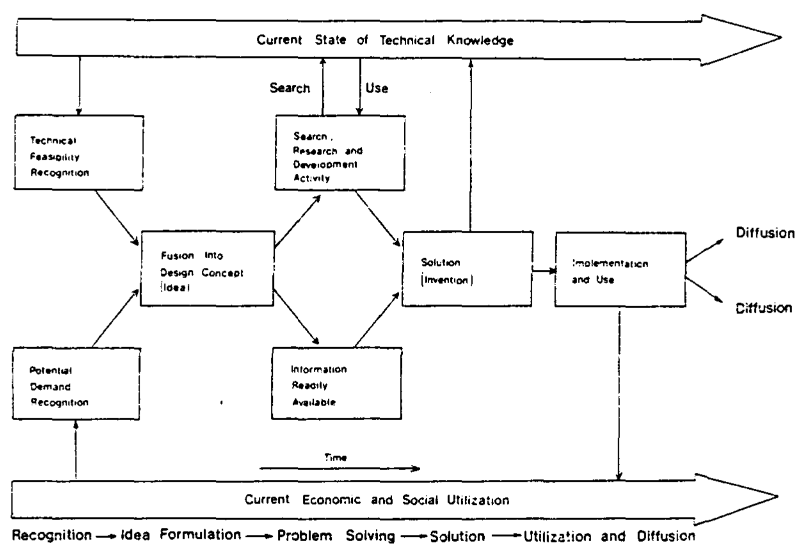


Fig 2.2. The innovation-development process (source: Brown, 1981).

In literature on technology development a similar debate is held on what is more important: demand or supply; technology-pull or technology-push? In the debate scientists generally stress the role of original research, while economists emphasize the role of (market) demand. R&D institutions do have a partly independent factor in the innovation process. Researchers might perceive a forthcoming problem and start research to find a solution. In other cases a problem or need rises high on a system's agenda through a political process, with subsequent funding of R&D activities: e.g. the initiation of R&D activities on solar energy as a reaction on environmental concerns. However, the influence of the users (demand) should be taken into account. In the inventive stages **adaptation** of the innovation to the needs and situations of potential adopters should take place. Detailed analysis of the development of new products and processes has shown that the resources for innovation lie both in the R&D system itself and in its environment: production and marketing systems, relations to suppliers, distributors and adopters. In some cases, users could even contribute a whole new solution or prototype to the innovation process. More often they can contribute ideas on use and practical problems.

Some companies recognize the value of this user resource and have created special programs to identify and encourage user innovation. In many cases, however, R&D-activities have been separated from diffusion activities and contact between R&D and users is severely limited. This institutional isolation is a particular problem of much R&D in developing nations (Gamser, 1988). Hierarchically structured (agricultural) extension programs have separated R&D from extension activities. This system creates barriers between R&D institutions and technology users (adopters). Technology users can often not obtain enough information on operating principles and possibilities from extension agents who are less knowledgable on the technology. On the other hand researchers often do not receive enough information about the needs of these users, practical operating experience or the constraints of the system they function in. This is especially the case if the users are part of the traditional (agricultural) sector. Scientists are generally educated and raised in the urban, 'modern' sector and are therefore not familiar with the actual circumstances and needs of the users. The result is often innovations that are not well adapted to local circumstances and waste of time and effort.

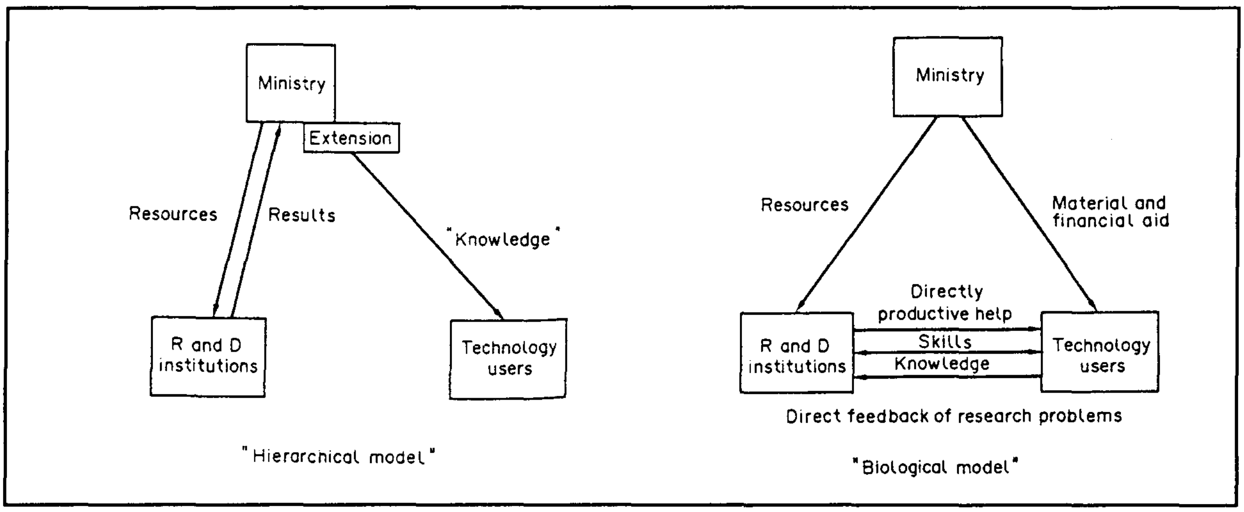


Fig 2.3. Hierarchical and biological model (source: Gamser, 1988)

In a less centralised system the relation between R&D and users is often closer. Gamser (1988) calls this a 'biological model' in which direct feedback between researchers and users occurs (see figure 2.3.). As described, many private companies have recognised the value of this user contact, giving them a competitive advantage. In an extremely decentralised system, local users may also invent and develop innovations themselves to solve their problems. These innovations can then be diffused through horizontal networks. Formal R&D activities may play a minor role, while R&D and adaptation (some use the term 're-invention') by users continues throughout the diffusion process. In agricultural innovations 'participatory approaches' try to tap into people's own priorities and problem solving capacities and support these with capital, institutional support and technical back-up. Some successes have been reached, especially in addressing poor peasant communities.

2.2.3. Goals and impacts of innovation diffusion

In paragraphs 2.2.1. and 2.2.2. it was argued that innovations are developed as a reaction on a certain need or problem. When evaluating the impacts of innovation diffusion, we will firstly be interested in the effectiveness of the innovation-development process: has the original problem been solved? If so then the direct impact of this innovation diffusion is the solution of the problem. If not: Why? Furthermore: Have there been any other (un)intended, (un)desired consequences? In paragraph 2.1.1. it was argued that diffusion is also a process of social change. Studying the impacts of innovation diffusion therefore also means studying the impacts on the diffusion system.

Since the number of problems to be solved is normally a lot larger than the means available, choices are made as to which problems to be solved and what target groups to be addressed. The question who benefits from the diffusion of innovations is therefore an important one. Many researchers have argued that the main part of the benefits is reaped by those that are already more affluent: the higher socio-economic groups, the industrialised nations. This is particularly important for developing countries. Part of this problem is ascribed to the fact that most innovation activities are located in and controlled by industrialised nations. Innovations are developed to solve problems in these countries and adapted to their circumstances and are therefore often not appropriate for developing nations. Also in developing nations much of the research and innovation is located in urban areas and controlled by urban elites, while the majority of the population lives in rural areas. Consequently most of the innovations are not developed to address the problems of these rural masses and/or are badly adapted to their circumstances.

In the R&D stage not only the problem to be addressed is chosen, but also the general form and size of an innovation. This has immediate consequences for the possible target group, especially through dependence on capital and infrastructure (e.g. electrical equipment, servicing needed), size, general price level (capital). Examples can be taken from agricultural extension programs in Third World countries, which are generally centralised, relying on technical experts to take decisions. Many agricultural innovations were based on 'green revolution' technologies, implying the use of plants with improved yields, but also artificial fertilizers, pesticides, etc. The capital intensiveness of these production techniques often made them only fit for large farmers. These profited, while smaller farmers often had to give up completely. Another part of the problem might not be ascribed to the nature of innovations developed, but to the strategies of diffusion agencies and their target groups for diffusing these innovations. Both private companies and government agencies generally focus their diffusion activities at those groups where the most success is likely. For private companies this success lies in profits and sales; for government companies e.g. in number of innovations diffused. Most often, in both cases, these target groups are the more advanced socio-economic groups. By early adoption, they are also likely to benefit the most from these innovations, increasing the existing gap between socio-economic groups.

This duality in the positive and negative sides of innovation diffusion can also be recognised on a macro-scale. There is general agreement in economic theory that (technological) innovation leads to productivity growth and consequently to economic growth. On a world-wide scale the economic progress is visible, but equally visible is the disparity in economic growth between industrialised and developing nations. Some of these developing nations have progressed enormously in some areas. In the 1960s and 1970s there were high hopes that this progress would trickle down to all groups and aid in decreasing the gap between socio-economic groups and countries. Several decades later this does not seem to be the case. Some even claim that the gap between 'rich' and 'poor' is increasing; that innovation leads to polarization instead of trickle-down of benefits.

The process of social change due to innovation diffusion can be illustrated in the development of infrastructure and market around innovations. Innovations are generally not developed once and then diffused, but often adapted and improved during the diffusion process; innovation is therefore a continuous process whereby form and function of an innovation, infrastructure and environment change over time, mutually influencing each other. A major process or product innovation can create a new industry. Development of the innovation progresses technologically as less radical follow-up innovations are introduced. These changes affect both the innovation, its market, infrastructure and the institutional environment. Along with these changes diffusion agencies will have to adapt their strategies in order to survive. Often a pattern in different stages can be recognised:

1. innovation: a period of very high uncertainty where trial-and-error problem solving leads to the innovation. Generally only a few firms are involved in this phase and facilities are small (garage/workshop level)
2. imitation: decreasing uncertainty as many new firms enter the industry and develop their own variants of the basic innovation which is gradually improved through continued R&D and by closer attention to marketing. New firms are often spin-offs from existing companies.
3. technological competition: improvement of innovation through production-process changes, while smaller firms find it difficult to enter the market.
4. standardisation: 'ideal' product has been found and R&D activities concentrate on improving production process, prolonging product life cycle. Technological competition has shifted to price competition.

The phases do not necessarily occur in a linear sequence. Switching forwards and backwards between phases occurs regularly. The development of solar water heating systems is a good example: this will be discussed in paragraph 3.1.

2.2.4. Institutional environment and policy instruments

In the preceding paragraphs, it was argued that institutions and aspects of the environment influence the development of the diffusion system both in terms of demand and supply aspects. It is of course impossible to describe all these influences, since they form too complex a set of factors, but it is possible to make a categorisation of important influences. The exact choice of important influences will vary with the technology to be diffused. Since this research also aims to identify options for stimulation of the diffusion process, a general description of possible instruments to this effect is given.

In the first place **general socio-economic circumstances** influence both demand and supply of technologies. Income level and distribution and social structure will determine the market structure. Business possibilities depend on the availability and costs of the inputs of raw materials, labour, machinery and capital. Education and skills of workers, employment structure and wages influence labour inputs. The availability of basic infrastructures (roads, energy, water, telecommunication, sanitation, etc) influence both the possibilities of businesses and clients (supply and demand); while the availability and costs of capital (interest and discount rates, see paragraph 3.7.) have a large influence on the willingness to invest by both suppliers and clients.

These socio-economic circumstances are in turn influenced by policies and actions of various institutions and vice versa. Especially **government and parastatal institutions** are often involved in trying to create what is called an 'enabling environment' for the diffusion of technologies; sometimes with specific programs, laws or subsidies, but many of their policies and actions influence the diffusion process unintendedly. In principle governments have four types of instruments for intervention (Hood, 1983):

- Nodality: the use of their central position in an information or social network, e.g. supply information to customers and manufacturers; organising exchange of information between R&D institutions and manufacturers;
- Authority: the use of legal or official power, i.e. the power to officially demand, forbid or guarantee (laws), e.g. by requiring certain technical standards, setting prices, forbidding imports of certain technologies; indirectly regulations in the field of work and wages for instance can have a large influence on production possibilities;
- Treasure: the use of financial instruments, e.g. using taxes and subsidies to promote or discourage the use of certain technologies, funding R&D projects, or buying products to guarantee a minimum market;
- Organisation: the use of government's stock of people, skills, land, materials and equipment in order to directly act physically, e.g. produce with parastatal companies, organise extension programs or organise R&D programs;

To stimulate the diffusion of certain technologies a mix of instruments will generally be used. The effectiveness of the various instruments and the mix depend on the circumstances and is hard to predict. To be able to design, monitor and adapt adequate policies government will need the **feedback of information** on impacts of policies and changing circumstances.

Institutions in the field of **R&D and education** influence the technological base in a country, educating skilled workers and engineers, developing new products, etc. Universities often perform both R&D and educational tasks at the same time and, hence, play a vital role in creating an adequate technological base for innovation. But other forms of education are equally important: polytechnics or similar institutions are required to train technically skilled people to perform the necessary production, installation and maintenance tasks involved in innovation diffusion. Additionally management and similar skills are required to run businesses and other organisations involved. Finally a population needs to have a general educational level in order to be able to understand and use certain innovations. Traditionally the role of R&D institutions has been the generation and adaptation of technologies from concept to prototype to production processes. Slowly more and more attention is given to the role of R&D institutions in the transfer and use of technologies, involving communication and cooperation with producers and users. This sometimes called the development and provision of 'infratechnology', i.e. technical information and services to serve industry and commerce such as engineering tables, calibration services, installation and performance standards, standardised measurement methods.

Other private and public institutions can also influence the diffusion system. In developing countries donor organisations and important NGOs are often involved in funding and organising extension programs, R&D efforts and other relevant projects.

Chapter 3 Solar water heating technology

In chapter 2 theories on the diffusion of innovations were discussed. This report concerns the diffusion of a specific energy technology: the solar water heater. Chapter 3 describes the main technical aspects of this technology. Before starting this description, a few aspects of energy technologies in general should be highlighted in paragraph 3.1. Paragraph 3.2. is dedicated to the solar radiation source. Paragraph 3.3. describes the principles of solar water heater technology. In paragraph 3.4. different types of system configurations and their advantages are described. Paragraph 3.5. describes different kinds of production technologies and materials that can be used for small-scale production of solar water heaters. Paragraph 3.6. discusses issues involving installation and maintenance. Paragraph 3.7. discusses the economics of solar water heating.

3.1. Introduction

Energy is never a goal in itself but an input necessary to meet certain needs of people. An energy technology then serves to convert an energy source into an output meeting these needs. Energy in general and renewable energy in particular have recently received increased attention, notably following publication of 'Our common future' the report of the World Commission on Environment and Development. This report put the concept of 'sustainable development' high on the development agenda. **'Sustainable development** is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). The report revived the discussion of saving the environment from the perspective of safeguarding the natural resource basis for future development. To do this natural resources and their real economic value should be made central to economic planning and investment, both public and private[6]. Within a sustainable development process, renewable energy technologies could play an important role. Renewable energy technologies use non-depletable sources of energy, such as wind, solar, biomass and hydro-power and therefore do not compromise the natural resource basis for future development. Solar water heating is one of these technologies. It is technologically far developed and widely diffused in many countries already. The technology is quite simple, in principle, making local production in technologically less-advanced countries very well possible. However, in most developing countries - despite the potential - solar water heaters have not been diffused widely, yet. The main obstacles seem not to be of a technological nature, but concern socio-economic issues.

---

6 In principle the lost benefits of alternative use or conservation of natural resources (alternative costs) should be integrated in the costs of these resources.

Solar water heating has occurred for a long time. The commercial market for solar systems has known many ups and downs. Solar heating of domestic water already appeared on a wider scale in the 1920s in Florida, USA. Up to the 1940s approximately 60000 systems were installed in the Miami area alone. Markets collapsed up to the 1960s, because the solar systems lost their economic advantage and because of negative publicity due to failing systems (Skarvedt, 1981). Markets got another boost in the 1970s and 1980s with the successive oil price shocks, clearly showing the economic logic behind installing solar systems. In a country like Israel, an extra reason for buying solar water heaters was to decrease Israel's dependence on imported arab oil. Every peak and valley also saw simultaneous developments of R&D and infrastructure. In the 1990s another boost to the solar market occurred due to environmental concerns. In 1992 an estimated 30 million m^2 of collector area for water heating has been installed world-wide (Gillet, 1993)mainly for domestic purposes. This represents a yearly market of around 1 billion US$. The main markets are in the USA, Australia, Japan, China, the mediterranean countries and the Western European countries. Production in the various countries started of on a small-scale basis for the domestic market, but gradually production levels were scaled up in several countries. By now countries, like Greece and Australia export a considerable part of their production. Thinking in terms of technology development stages (paragraph 2.2.3), solar water heating has reached the 'technological competition' or even 'standardisation' stage (3 or 4) in these countries. In other countries, especially several developing countries, the technology still has to grow from its initial stages.

The different technological development stage of solar water heating in industrial and developing countries is reflected in Research and Development (R&D) efforts. These focus on improvement of certain performance characteristics, while no revolutionary breakthroughs are expected. The main interest in industrialized countries is on:

- ways of extending life-time by neutralizing or avoiding corrosion;
- designs which can produce hot water (steam) at 'high' temperatures (in the order of 150 °C), which would open up the industrial market;
- materials that will maximize overall efficiency and thus allow a reduction of collector area, while optimizing costs;

In developing countries R&D generally focuses on:

- ways of replacing highly sophisticated and imported materials with locally available substitutes;
- ways of reducing prices by using cheaper materials, simple designs and labour intensive manufacturing processes;
- ways of extending life-time;
- extremely simple and cheap systems for poor households now using non-commercial energy for (limited) water heating;

3.2. Solar radiation

The first step in investigating the potential of solar water heaters is assessment of the resource: the sun. Solar radiation is characterised by its variability. Obviously at night no sunlight reaches a certain surface, but also during the day-time this amount varies. First the mechanisms that influence the angle of incidence and intensity of solar radiation reaching a surface will be described. After that the use of aggregated solar radiation data will be discussed.

Incidence of solar radiation

Every day an amount of solar energy reaches the earth that could meet the world's energy demand several thousands of times. Around 1367 W per m^2 of solar energy reaches the outer layer of the earth's atmosphere; this is called the solar constant (G_{sc}). At midday, on a clear cloudless day a maximum of approximately 1000 W per m^2 of solar radiation reaches the earth's surface. At night the amount of solar radiation reaching the earth's surface is reduced to practically 0. The solar radiation reaching a horizontal surface on the earth varies between these two extremes.

The part of the solar radiation that reaches the earth's surface in a direct beam from the sun is called beam radiation: G_b. G_b is measured in a plane perpendicular to the sun's direction. Due to reflection and scattering from sky and ground, some of the solar radiation will reach the surface indirectly and under various angles. This is called diffuse radiation: G_d. The total solar radiation reaching a fixed, tilted surface - like a solar water heater - is the sum of beam and diffuse radiation. Of the beam radiation, only the part perpendicular to the fixed surface is useful:

$$G = G_b.\cos\theta + G_d$$

where θ is the angle of incidence that the sun's radiation makes with the normal to the surface. This angle of incidence varies with position and time. Figure 3.1. shows the important angles to calculate the angle of incidence.

- β **slope (or inclination)**: angle between the surface in question and the horizontal;
- γ **surface azimuth angle (or orientation)**: the deviation from the local meridian of the projection of the normal to the surface on a horizontal plane; with zero due south, east negative;
- θ_z **zenith angle**: the angle between the vertical and the line to the sun, which is the complement to the 'height' the sun has reached in the sky;
- γ_s **solar azimuth angle**: the angular displacement from the south of the projection of beam radiation on the horizontal plane; zero due south, east of south negative;

Then: $\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$

β and γ are determined by the fixation of the collector. γ_s and θ_z are determined by the position of the sun in the sky and can be calculated using the following formulas:

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$$

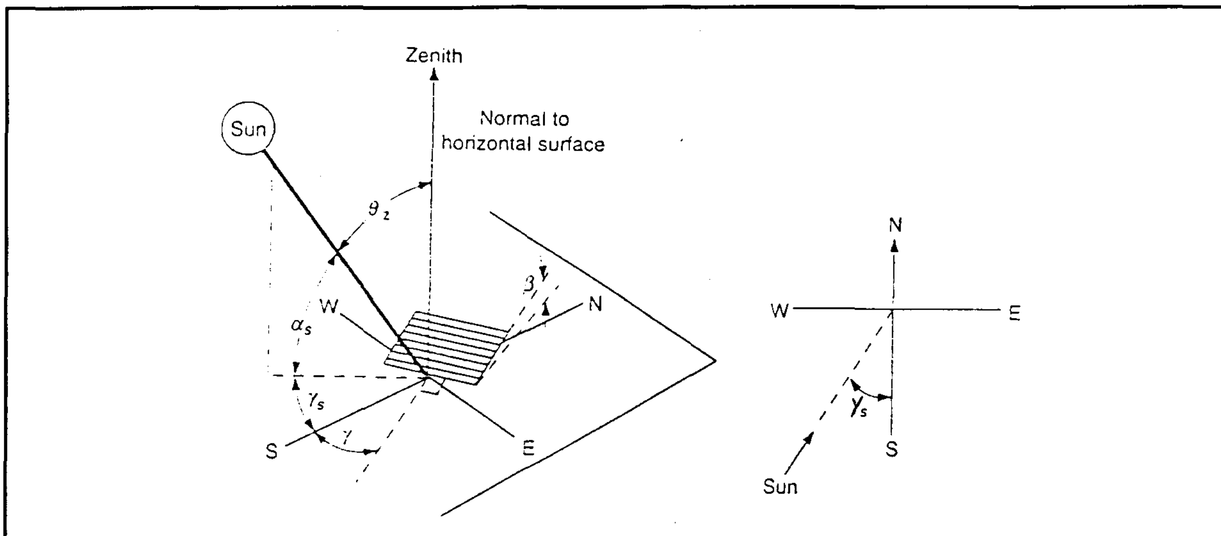


Fig 3.1. a) angles for a tilted surface; b) solar azimuth angle in plan view (source: Duffie, 1993).

$\sin\gamma_s = \cos\delta\sin\omega/\sin\theta_z$, where

- ϕ **latitude**: the angular location north or south of the equator (north positive);
- ω **hour angle**: angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis: 15° per hour away from solar noon, when the sun is at its daily highest point in the sky; morning negative;
- δ **declination angle**: the angular position of the sun at solar noon with respect to the plane of the equator, north positive; due to the seasonal displacement of the earth' axis in relation to the sun: during the year the declination angle changes between 23.45° north and south.

Intensity of solar radiation

Another influence on the useful radiation on a tilted surface, is the intensity of radiation G_b and G_d. In the first place there is a slight variation (ca. 3.5% around G_{sc}) in the amount of solar energy reaching the outer layers of the earth' atmosphere due to the seasonal variation in the distance between sun and earth. More important, however, the radiation reaching earth's surface passes through the atmosphere, where scattering, and absorption extinction takes place. Scattering deflects radiation from its direct path, partly reflecting back into space, partly scattering to earth causing diffuse radiation. Scattering takes mainly place on air molecules and on water and dust particles. Absorption in the atmosphere is mainly due to ozone, water vapour and carbon dioxide, particularly absorbing almost completely all short-wave radiation (ultraviolet, etc.) The extinction of beam radiation can be expressed in an exponential function:

$$G_b = G_{sc} \exp [-(P/P_0)(B/\cos\theta_z)$$

where B is the extinction coefficient, including scattering and absorption factors. The variation in place and time of humidity and dust particles in the atmosphere causes the most variation in B. Generally this coefficient is tabulated as an average per geographical area and month. P/P_0 is a measure of altitude; together with the zenith angle (θ_z), the altitude determines the path length of the radiation through the atmosphere and, hence, the extinction.

Diffuse radiation (G_d) is even more difficult to calculate from atmospheric data. In general it can be said that as a day becomes cloudier more beam radiation is absorbed and scattered: beam radiation decreases, but diffuse radiation will rise. The total radiation will decrease.

Solar radiation data

The formulas in paragraph 3.2.1. were for instantaneous solar radiation, i.e. power output (W/m^2). To calculate the energy gain of a solar system, radiation figures integrated over time are needed. This requires figures on the variation of solar radiation and the hours of sunshine. Especially at high latitudes, the number of sunshine hours per day varies considerably during the season. Generally speaking countries between 15° and 35° North and 15° and 35° South latitudes have the highest levels of total radiation per year. The next most favourable region is the equatorial belt between 15° North and 15° South latitudes. In this region the humidity is higher and the clouds are more frequent; Tanzania and Kenya lie in this region.

Since the integration over time of all these variables makes for cumbersome calculations, past measurements of radiation data are generally used to make performance predictions for the future. Radiation data is generally available in monthly average daily total solar radiation and/or in hourly total radiation - both on a horizontal surface. Then calculations can be made for radiation on sloped surfaces. Especially at high latitudes maximizing yearly energy gain will require considerable 'sloping' of the systems. As a 'rule of thumb' the maximum yearly energy yield will be gained at a slope approximately equal to the latitude. The corresponding optimum azimuth angle (orientation) will be 0° in the northern hemisphere (facing south) and 180° in the southern hemisphere[7].

Care should be taken using solar radiation data because uncertainties in measurement equipment and integration methods can be considerable. Duffie (1993) estimates that modern (post-1970), high-quality data have measurements good to ± 5%. The accuracy of older data is often less desirable and generally no better than ± 10% and for some stations ± 20%.

---

[7] for The Netherlands a surface tilted at 45° and directed towards the south will receive ca. 13% more energy per year on average than a horizontal surface (Velds, KNMI, 1992).

3.3. Solar water heating technology

Solar water heaters use both diffuse and beam solar radiation, do not need tracking devices and are therefore easy to install and maintain. They are almost always mounted in a stationary position with an orientation optimized for the location and the time of the day and year it is supposed to operate. The basic operating principles of a solar collector are radiation and heat transfer mechanisms. It is a special kind if heat exchanger that transforms radiation energy into heat in the absorber, which is then transferred to a fluid. The efficiency of a collector (over a specified time) is the useful energy divided by the incident radiation energy:

$$\eta = (\int Q_u dt)/(A \int G_T dt)$$

where Q_u = the useful energy output
A = the collector area
G_T = total radiation on the tilted collector surface

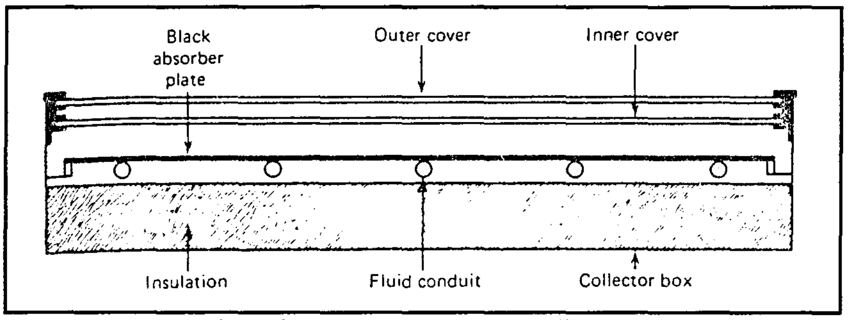


Fig 3.2. Cross-section of a solar water heater collector (source: Duffie, 1993)

Figure 3.2. shows a basic solar water heater collector: it is essentially made up of a 'black' solar energy absorber, where the solar radiation is absorbed, converted into heat and transferred to a fluid (often water but other fluids are also used e.g. glycol). The collector is heated up above ambient temperature and starts loosing heat to the environment. Generally the absorber is protected from the environment by a transparent cover, reducing the convection and radiation heat losses. The back and sides of the absorber are generally covered with insulating material to reduce conduction heat losses. A box is used to protect and keep absorber, insulation and cover plate together. In most cases an insulated tank - sometimes integrated with the absorber - is used to store the hot water and (insulated) pipes are used to connect collector and tank.

The basic energy balance of solar collector in steady state is ruled by the difference between solar energy absorbed and thermal losses:

$$Q_u = A\, F_r[S - U_L(T_i - T_a)]$$

where S = solar energy absorbed per unit area
T_i = fluid inlet temperature
T_a = ambient temperature
U_L = overall heat loss coefficient
F_r = collector heat removal factor

Solar energy absorbed: optical losses

Optical energy losses have to do with the solar radiation reaching the collector (G_T) and being absorbed. Covers are generally used to reduce heat losses from the collector, but at the interfaces of cover and air reflection of solar radiation occurs, depending on the refractive index of the cover used and the angle of incidence. The most common cover material is glass. In the cover itself solar radiation is absorbed, dependent on the material and the path-length; path-length in turn is dependent on the thickness of the cover and the angle of incidence. The total transmittance - i.e. fraction of the radiation not reflected or absorbed - can be expressed in one factor: τ, which for most collectors will be around .9 to .95.

Finally the transmitted radiation has to be absorbed. Some of the transmitted radiation will be reflected at the absorber surface, however. The absorption is dependent on the absorber material (notably the coating and the surface structure), the angle of incidence and wave-length of the radiation. By using dark coated surfaces a total absorption coefficient α of ca. .95 or more can be reached. High absorption values mean high emittance values: the collector will loose heat by thermal radiation being emitted. However, the wavelength of the emitted thermal radiation is considerably longer than that of the absorbed solar radiation (.3 to 3 μm). At normal operating temperatures (up to 100°C), less than 1% of the emitted radiation is of wave-lengths shorter than 3 μm. This introduces the possibility of choosing selective absorber paints that absorb well in the range of solar wave-lengths, but emit little in the thermal radiation range. The most commonly used selective paints are black-nickel and black-chrome. Adding a surface structure - by grooving or pitting - is another way to increase the solar absorption, but might also increase emittance of heat radiation. In general it is more critical to have high absorption of solar radiation, than low emittance of heat radiation.

Transmittance and absorption can be combined into one factor: $(\tau\alpha)$, the transmittance-absorption coefficient. Because the coefficients are dependent on the angle of incidence of solar radiation, separate coefficients should be calculated for beam, diffuse and reflected radiation and for different circumstances. On average 10 to 15% of the solar radiation is lost through optical losses.

Heat losses: radiation and convection

Because solar radiation is absorbed and converted into heat, the temperature of the absorber rises; when the absorber temperature is higher than the fluid temperature, heat will be transferred from the absorber to the fluid. But with the rise above ambient temperature, the collector will also start loosing heat to the surroundings. To reduce heat losses transparent covers are used on the front and opaque insulation on the bottom and edges. In a well designed flat-plate collector, the main part of the thermal losses will be through the front cover (80 - 90%). The two main mechanisms for these thermal losses are thermal radiation and convection.

The heated absorber will emit long-wave radiation to the cover, which is partly reflected, partly transmitted and partly absorbed by the transparent cover. Thermal radiation is emitted by a body by virtue of their temperature. If the temperature becomes higher, more radiation will be emitted and its distribution will show more radiation with short wave-lengths (i.e. more energy is emitted). Both the collector and its surroundings will emit such radiation. The net radiant heat loss will therefore be dependent on the temperature difference between absorber, cover and surroundings. For the temperature range of collectors and surroundings, the emitted radiation will mainly be in the infrared spectre, which is in large part reflected by glass covers. The use of selective surfaces will considerably reduce radiant heat losses (see figure 3.3.)

The rate of convective heat loss by the absorber is depends on the natural convection by the flow of air between the absorber and the cover. Solving equations for inclined collectors involves complex calculations, including the temperature difference, the plate spacing, geometry and properties of the convection medium (generally air). If a cover is used the convective heat losses of the absorber (and part of the radiative heat losses) will heat up the cover. This in turn will start loosing heat to its surroundings both by convection and radiation. The heat loss of covers exposed to outdoor conditions is very dependent on wind speed[8]. All in all the upward heat losses can be summarized in a linear equation: $Q_L = Ah(T_i - T_a)$

consisting of four components: radiation from the absorber and natural convection from absorber to cover (q_{rad} and q_{conv}), resulting in heating of the cover and subsequent heat loss by wind convection and radiation (q_{wind} and q_{rad}). For an illustration of the mechanisms see figure 3.3. In absence of a selective coating, radiation by the absorber is the dominant mode of heat loss; with such a surface convection is the dominant mode. Other ways of reducing heat losses are using more than one cover and the suppression of natural convection by using transparent honeycomb insulation materials between absorber and cover to reduce the free flow of air. In general the suppression of heat losses can be achieved by keeping the absorber temperature low (as compared to the surroundings); this can be achieved by good heat transfer to the working fluid and by a low operating temperature of the fluid.. Therefore, the higher the temperature to be achieved by the solar water heating system, the higher the heat losses.

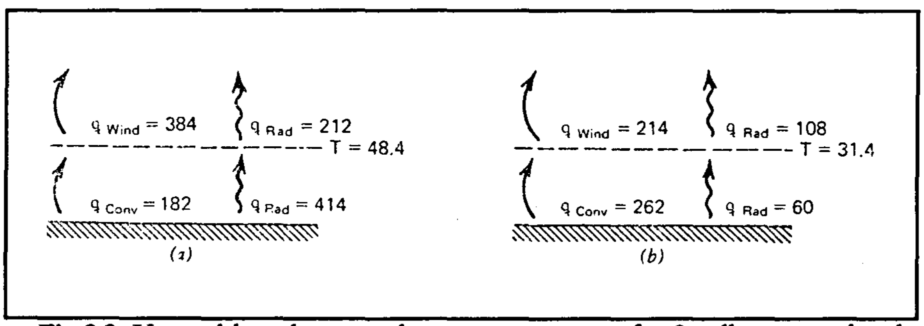


Fig 3.3. Upward heat losses and cover temperature for 2 collectors under the same radiation, wind conditions and absorber temperature (60°C). a) emittance: 0,95; b) selective coating, emittance: 0,10. (source: Duffie, 1993)

8 Wamuff e.a. (1977, in Duffie, 1993) report a (wind) convection coefficient: $h_v = 2.8 + 3.0\ V$, where V is the wind speed in m/s.

Heat exchange from absorber to fluid

In the preceding chapter it has been shown that thermal losses depend on the temperature difference between absorber and surroundings. This in turn depends both on the radiation absorbed and the effectiveness of heat transferred to the fluid. In the collector energy balance this effectiveness is expressed as the heat removal factor: F_r; this is the ratio of actual useful energy gain to the maximum useful energy gain if the whole collector would have been at the fluid inlet temperature. Since heat exchange and removal is not perfect, part of the absorbed energy is used to heat up the absorber above fluid inlet temperature, thereby increasing heat losses. As an illustration, the case of an absorber with parallel tubes is taken. Figure 3.4. shows a cross section of an absorber with one tube and the relevant factors.

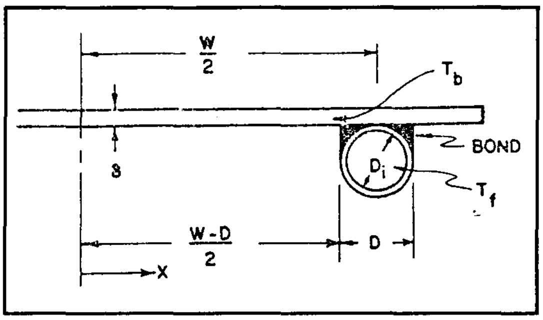


Fig 3.4. Absorber fin, bond and tube (source: Duffie, 1993)

W/2	= half distance between tubes
D	= outside diameter of the tubes
(W-D)/2	= called the fin
D_i	= inside diameter of the tubes
δ	= thickness of the absorber plate
T_b	= temperature above the bond
T_f	= fluid temperature
k	= plate thermal conductivity

Heat has to be transferred from the absorber to the tubes. If the plate is made of well conducting material, adequate thickness and the distance between the tubes is not too wide, the temperature gradient in the plate will be negligible and the whole plate can be assumed at temperature T_b. The energy absorbed in the fin and above the tube 'flows' in two directions: to the surroundings, where it will find heat conductance U_L (the overall heat loss coefficient); and to the fluid, where it will find the absorber-to-fluid heat conductance U_o; made up of heat conductance of the plate, the heat conductance of the bond between plate and tube and the tube-to-fluid heat conductance. Especially a high bond conductance has proven to be important for the performance of collectors. With these physical characteristics a collector efficiency factor (F') can be defined, which is the ratio between the overall heat loss coefficient and the absorber-to-fluid heat conductance; F' is little dependent on temperature and essentially a constant for a collector: $F' = U_o/U_L$

The fluid enters the collector at temperature T_{fi}, but as it flows through the collector its temperature will rise as heat is absorbed. As the fluid temperature rises in the flow direction, so will the absorber temperature and subsequently heat losses will increase. The fluid will leave the collector at T_{fo}. The rise in temperature will depend upon the mass flow rate and heat capacity of the fluid and the length of the collector in the flow direction. These can be put together to calculate a collector flow factor: F". Finally, the collector heat removal factor is made up of the collector efficiency factor and the collector flow factor: $F_r = F'F''$

where F" is a measure for the increase in heat loss due to the temperature rise from fluid inlet temperature, while F' is a measure for the increase in heat loss due to the temperature difference between absorber and fluid perpendicular to the flow direction.

Instantaneous and overall efficiency

In the preceding paragraphs, the performance and efficiency of solar collectors in steady state has been discussed. In practise, however, the operation of solar collectors is far from steady-state. Important variations will be caused by the intermittent behaviour of solar radiation and wind. Also the changes in ambient temperature - e.g. between day and night - cause heat capacity effects. Finally, the fluid inlet temperature can change because of heating through the day, but also because of use (tapping off) of hot water. The efficiency of a collector is therefore not a constant. To be able to predict collector efficiency under different circumstances and assist in comparison, design and monitoring, several models for collector characterisation have been developed. Most of the solar water heaters produced in the industrialized countries have been tested according to the ASHRAE 93-77[9] norms. This is a test for the instantaneous efficiency of a solar water heater at different temperatures; with these results an overall efficiency can be calculated. The variables used include temperature dependent heat loss factors and an angular dependent absorption-transmittance coefficient as described in the preceding paragraphs. Duffie (1980) describes a design method - known as the f-chart method - to estimate the long-term (yearly) performance of solar water heating systems, under different radiation conditions, using these test data. However, the model does not include realistic performance characteristics, such as wind speeds and different patterns of hot water use. Other test methods exist taking such data into account, such as the one TNO and International Organization for Standardization (ISO) are developing for complete hot water systems under realistic user conditions. Proctor (1984, in Duffie, 1993) has written a detailed discussion of instruments used in tests and concludes that uncertainties in radiation measurements dominate uncertainties.

As a very rough average in the very best designs some 10-15% of energy is lost due to optical losses and about 15-20% through thermal losses. This makes a maximum efficiency of about 65-75%. Most simple collectors only achieve up to 50% efficiency at a water temperature of about 60 °C, while selectively coated collectors achieve 55 to 65%. Optimization of a solar water heater design is essentially a matter of minimizing energy losses against increasing costs. In practise other considerations will also play an important role. Extreme situations of boiling and freezing might have to be considered. The collector will have to be able to resist such conditions if necessary safety measures have to be taken. Other important design factors are: mechanical strength of collector envelope and cover; durability of cover, insulation, absorber and (selective) coating; resistance of collectors to corrosion. In the next paragraphs some indications of performance and costs of different collector types and water heating systems will be discussed.

---

9 American Society of Heating, Refrigerating and Air-Conditioning Engineers; ASHRAE 1976 System Handbook, New York, 1976; described in Dickinson, 1980.

3.4. Solar water heating systems

Solar water heating systems can be classified into different types: see figure 3.5.

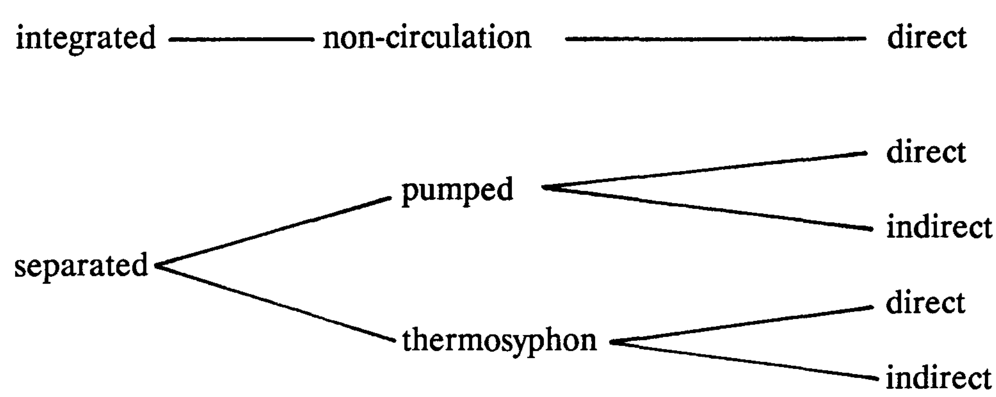


Fig 3.5. Classification of solar water heaters (source: Andersson, 1984).

Integrated solar water heaters have the collector and the hot water tank in the same unit. Almost all integrated systems are directly filled with the water to be heated. The water does not circulate but stays in the hot water tank which is heated. The simplest solar water heaters belonging to this group is the black plastic bag that can be put into the sun to get hot water in the afternoon. More advanced designs generally contain a black water tank in an insulated box with a transparent cover and can be connected to the water supply. The fact that the water does not circulate makes the device less susceptible to damage by low quality water. The systems are also generally cheaper and easier to install and maintain. The disadvantage is that efficiency is generally a lot lower than for separated systems, even with addition of cover and insulation.

Separated systems have a collector and a hot water tank separately. This introduces the possibility to insulate the hot water tank well keeping the water hot, especially over night. If these separated systems are well designed, the cold water will be in the lower part of the tank, while the hot water for consumption will leave the tank at the top, creating a temperature gradient called stratification. Assuring that the cold water will flow through the collector will reduce the fluid inlet temperature and thereby heat losses. Van Koppen e.a. (1979, in Duffie, 1991) have shown that systems with low flow - that inherently have a lower heat removal factor but remain better stratification through less mixing - might give a better net performance. Generally it is easier to maintain good stratification with direct, thermosyphon systems.

All separated systems are based upon the circulation of the working fluid (water or otherwise, see next paragraph) through the collector, thereby removing the heat from the collector and keeping its temperature low. The circulation can either be forced - with pumps - or natural - thermosyphonic. The thermosyphon system works on the basis of the lower density of heated fluid; in other words: if the collector fluid is heated by the sun, this fluid is lighter than cold fluid and will have the tendency to rise. If the tank is well placed above the collector and the piping system does not obstruct its path (no airlocks or reverse gradients), a continuous circulation through the collector will be established, as long as the fluid is still heated. When the intensity of the solar radiation lowers, the circulation will stop. If properly designed and installed, no circulation in the opposite direction will occur, thereby preventing heat loss over night. This system is therefore self-regulating, without pumps or controls. The circulation can also be forced with a pump - generally electric. This has the advantage that the tank does not have to be placed above the collector, which makes these systems architecturally more versatile. Most collectors are installed on the roof of buildings to prevent shading and damage to the collectors. However, the roof may not be strong enough to carry the weight of a large water storage tank. The circulation of fluid through the collector has to be stopped when the water is no longer heated. Generally this is done with differential thermostat that measures the temperature difference between water in the tank and fluid coming out of the collectors; switching off the pumps when the temperature difference is below a certain value and switching it back on when this difference is above another minimum value. The pump and controls make the system somewhat more expensive and dependent on reliable electricity supply. On top of that the increased complexity of the system makes for more maintenance and repair. Pumped systems will generally be preferred for large centralized systems, mainly due to the problems of placing tanks and collectors.

In a direct system cold water is filled into the water tank, circulated and heated in the collector and then used by the consumer. In an indirect system the fluid passing through the collector is not the same as the water heated and consumed. Generally this fluid is a mix of (high quality) water and glycol or another fluid with corrosion prevention and anti-freezing characteristics. The heat transferred from the collector to this fluid is further transferred to the water by a heat exchanger in the hot water tank. Due to this additional heat exchange step, the thermal performance of indirect systems is generally lower than that of direct systems, but if well designed this should not be more than a few percent (Duffie, 1980). The advantage of indirect systems is that the collector's narrow piping system is protected from low quality, calcareous, corrosive or dirty water, that can clog up or corrode the collector or in other ways affect its heat exchanging abilities[10]. This will increase the life-time of the system and its thermal efficiency will be less affected. Also the system will be protected against damage through freezing in cold climates. Needless to say that with the increased complexity indirect systems are generally more expensive. The use of fluids other than water in the collector circuit will demand careful design to prevent leaking into the consumable water, particularly if the water is to be potable.

---

10 Corrosion prevention can also be achieved by choosing corrosion resistant materials, like copper, or adding sacrificial anodes. Clogging of pipes can be prevented by increasing the pipe dimensions, thereby increasing the material cost however. Clogging up with dirt can also be fought by regularly 'flushing' the system. Experience in many countries (a.o. Kenya and Turkey) is that indirect systems with sacrificial anodes are becoming more and more common. The life-time of such systems can be up to 15 years or more, instead of 2-3 years in a direct system if the water quality is low (Andersson, 1984).

Two more distinctions can be added for all of these solar water heating systems: pressurized vs. non-pressurised and stand-alone or with a back-up energy source.

Pressurized systems are directly connected to the public water line or a high placed cold water storage tank. The tank is immediately refilled with cold water when hot water is tapped of. If the system is designed well the cold water will enter at the lower part of the tank, while the hot water will leave the tank at the top, thereby assuring that the hottest water is always available for use and the coldest water is circulated through the collector (reducing collector temperature and thereby heat losses). This temperature gradient in the tank is called stratification and should be maintained to increase overall efficiency of the system. The pressure on the system depends on the pressure of the public line or the height of the cold water storage tank. A system can also be made non-pressurised by adding a floater in a combined filler/expansion tank, which opens the water supply when hot water is drained. The tap can also be manually or electronically controlled. A high pressure increases the demands on the strength of the system design and material use. Pressurized systems do have the advantage, however, of being self-regulating and maintaining the pressure on the hot water line.

In principle a solar water heater, consisting of an absorber and a tank, can - if well designed - deliver hot water regularly. Since solar radiation is not constant, however, such a stand-alone system will deliver more or hotter water on sunny than on cloudy days: the temperature will vary and on some days - especially cold, cloudy days, when the demand for hot water is often higher - the required temperature or amount of hot water might not be reached. This might be allowed in rural areas where demands on hot water are less strict. But an urban environment the solar system has to compete with conventional - electric - water heaters that are capable of supplying hot water every time, making a day without hot water less accepted. Requirements set by the consumer are therefore very important when designing solar water heaters. One way of avoiding such situations is oversizing the system (using up to two times the collector area than is required from average consumption and radiation figures). This will increase costs considerably, however. Another, often cheaper solution, is to add a back-up energy source: often an integrated electric immersion heater with a thermostat that will turn on when the temperature falls below a certain minimum value. Temperature regulation with these integrated auxiliary heaters is very important: if the electric heater is switched on too soon (i.e. at if the water temperature is still relatively high), too much use will be made of electricity to heat the water and the energy saving advantages will be lost; similarly, if the water temperature is heated too high with electricity, the collector losses will increase and less energy will be saved. Alternatively, if the heater switches on too late (i.e. if the water temperature is too low already), the water will be too cold for the consumer's needs and the additional investment in a back-up heater has turned out to be useless[11]. Auxiliary heaters should be placed in the top part of the tank to remain stratification. This is generally easiest with an integrated electric immersion heater. Also temperature control is generally easiest with electric back-up heaters.

---

11 Apart from efficiency considerations, other considerations might play a role too. In many Westeuropean countries for instance, boiler temperatures are required to be kept at a minimum of 60 to 65 °C to kill legionella bacteria.

3.5. Absorber types, material issues: durability and efficiency

When designing a solar water heating system, apart from the system options discussed before, options between various designs of the absorber and materials to be used are possible. The options will be discussed shortly - at least those options that are the most likely to be used for local production in developing countries - including some of their consequences for efficiency, durability, production and costs. Another limitation is that only separated systems will be discussed.

Types of absorbers

The snake or zig-zag absorber is the absorber which can be constructed using a minimum of tools. The piping can be made out of any type of metal piping, that will be bent preferably using a bending machine, but not necessarily. The bent pipe is soldered or wired to the absorber. Soldering is preferred, since it leads to a better thermal bondage than wiring and therefore to a higher efficiency. This type of absorber is the most easy to make, costing the least amount of time, tools and skills. The disadvantage is that its efficiency is lower than that of other absorber types.

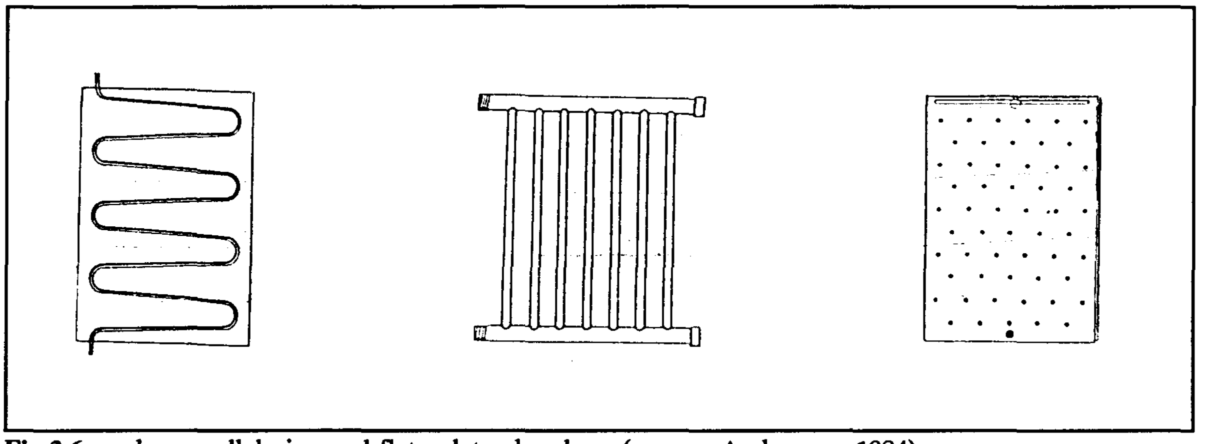


Fig 3.6. snake, parallel pipe and flate plate absorbers (source: Andersson, 1984)

A tubular register or parallel pipe type absorber is essentially made of two horizontal, 'header' pipes and several vertical 'riser' pipes. If T-fittings are available and not too expensive, the header and riser pipes can be connected by soft-soldering. Otherwise holes are drilled in the header pipes and - depending on the kind of pipe (copper, aluminium, galvanized steel) - the riser pipes are welded or hard-soldered to the header pipes. This has to be done very accurately to avoid leaking of the connections in the future. With galvanized steel the danger exists that the galvanization layer of zinc is removed by the welding process, which would lead to quick corrosion in the future. Tubular register absorbers are more difficult to make, but generally have a higher efficiency. The pipes can be wired or soldered to the absorber plate or plate strips can be interwoven into the tubular register pipes. The tubes can also be clamped, i.e. pressed into the grooved absorber. This means an extra production step however.

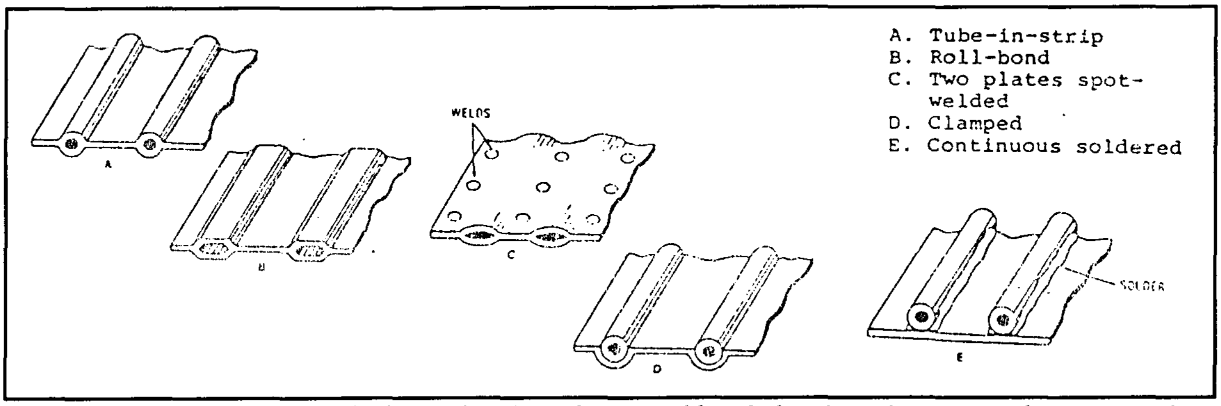


Fig 3.7. tube-in-strip, roll-bond, clamped and continuous soldered absorbers (source: Andersson, 1984)

In the tube-in-strip and roll-bond designs, the tubes are made by pressure expanding the absorber plate. This requires specialized, capital-intensive production equipment and seems therefore less suited for production in many developing countries.

In the case of flat-plate or sheet absorber, the water does not flow through a piping system, but directly between two plates that are held together by spot-welding soldering or using bolts. The efficiency is generally a bit lower than that of tubular absorbers. The disadvantage of these absorbers is that they use up a lot more working time, energy and tools. Also various such designs have proven sensitive to leaking.

Streib (1989) presents a detailed overview of the influence of the various design parameters on the efficiency of the solar water heater. The case of comparison (or 'standard' system) is a tubular register absorber made of copper, with an overall efficiency of 48 %. The various design parameters have been individually tested against this 'standard' system. Table 3.1. (page 38) is mainly based on these findings.

Materials used

The materials used most often for solar water heaters in developing countries are: galvanized or stainless steel, aluminium and copper or copper alloys.

Copper has the best heat conducting characteristics and will generally lead to a higher efficiency collector. It also has the advantage of good corrosion resistance, which is particularly important for direct systems being used in areas of low quality water. Some copper alloys (notably copper-nickel) have even better corrosion resistant characteristics. Therefore copper is generally the preferred material for collector water ways - from a technical point of view. The disadvantage of copper is its high price (in Tanzania 2 to 3 times the price of galvanized steel) and, in some countries, difficult availability.

Aluminium has a lower heat conductivity and is also more sensitive to corrosion. It is however easier to work with than copper and steel and - generally - considerably cheaper than copper. Aluminium was for instance often used in systems produced in Israel. Availability might also be a problem, especially with aluminium pipes.

Stainless steel - if the right grade is chosen - can be at least as corrosion resistant as copper, but its price is often quite high too, especially in developing countries, where it has to be imported. Its heat conductivity is considerably lower than copper. Availability can also be a problem. Therefore stainless steel is seldom used in collectors produced in developing countries.

A material that is often used in developing countries - for storage tanks as well as collectors and piping - is galvanized steel. Technical manuals (f.i. Skartvedt, 1981) often advice to avoid galvanized steel, since it corrodes easily in low quality water and its also very sensitive to galvanic corrosion[12]. However galvanized steel is generally much cheaper and readily available in most areas. The use of indirect systems and cathodic protection will protect the galvanized steel from corrosion. However, also galvanized steel systems have been reported to perform for more than 10 years in several developing countries without such protection measures.

Plastics are used in many industrialized countries to produce cheap solar water heaters. They are generally very well resistant to corrosion by water and if also resistant to radiation against UV-radiation they can have a very long life-time. Their efficiency is generally somewhat lower, since plastics are not very good heat conductors. Since the production requires some quite capital intensive equipment, these are generally not suited for production in developing countries.

Another effect that deteriorates the performance of solar water heaters, is scalding or the deposition of calcareous layers on the inside of absorbers, heat exchangers and tanks. Especially in the narrow absorber pipes this can lead to blocking of the pipes and to deterioration of the heat exchange between metal and water. This effect increases as the water reaches boiling temperatures (> 80 °C), which can easily happen with efficient absorbers, on sunny days and with little to no hot water use. Treatment of the water, use of indirect systems and - in general - limitation of the temperature can prevent this problem.

Absorber paints

To maximize radiation absorption and reduce reradiation, the absorber is generally painted black. An ordinary black paint reflects less radiation than a glossy paint. Spraying paint gives an even better result than painting. There is special selective paints that maximize absorption and minimize reradiation and therefore heat losses. They can increase collector efficiency with as much as 15%, especially on cloudy days with a lot of diffuse radiation and at very high temperatures. These paints are a lot more expensive, however, and generally not readily available in most developing countries. Very important with all paints used, is preparing the metal well to create a long lasting bondage between metal and paint.

[12] electro-chemical or galvanic corrosion arises if two dissimilar metals are in direct contact: especially steel-copper or aluminium-copper. Solutions are to use rubber or plastic packings or special welding materials to separate the two metals. However also water containing a lot of copper ions is supposed to corrode galvanised steel: f.i. a copper absorber and a galvanised steel water tank.

design parameter	influence on efficiency	Other remarks
absorber type		
zig-zag	- 6 %	easier production less operational problems
tubular	standard	
plate	- 2 %	
connection of pipes and plate		
wire loops	- 7 %	easier production
interweaving	standard	
soldering	+ 2 %	should be done carefully to get good, lasting bondage
absorber material used		
iron/steel	- 10 %	less costly, more easily available, but corrosion sensitive
aluminium	- 4 %	
copper	standard	
paint used		
mat black - sprayed	standard	
mat black-painted	- 1 %	
selective coating	up to + 15% better	much more costly; availability?

Table 3.1. influence of several design parameters on efficiency (source: Streib, 1989)

3.6. Installation and maintenance

While local production, installation and maintenance are in principle - technically - rather straightforward, experiences with solar water heaters in developing countries have often been bad. In some cases designs and material quality is low, but in many cases it seems to go wrong with installation and maintenance.

Firstly, important before installation is the right sizing and choice of the system. This requires firstly the assessment of the hot water demand of a prospective client: amounts, temperature of the hot water and time of consumption. With data on cold water supply temperatures the thermal energy demand can then be calculated. Then the expected solar energy contribution can be calculated using reliable efficiency and solar radiation data. This can first be done roughly to assess global potential; then it has to be assessed together with questions on choice of system type, reliability of hot water supply required (auxiliary heating?) and place of installation. Numerous design methods have been developed (see Duffie, 1993). System sizing and choice requires expertise and experience. For standard size solar water heaters for households, the system sizing is less sensitive. System design and sizing becomes far more important for large, commercial or industrial systems because of the high investment costs and possible savings involved. In developing countries, sometimes solar data of a certain area is not readily available. In many cases no data on system efficiency is known (especially if it is locally produced panels). In those cases experience with using and sizing the system will have to replace calculations.

After that important questions include where to install the systems, avoiding shading and damage, including architectural considerations and maintaining the possibility of future maintenance and repair. Also important are angle of inclination and orientation. In many cases the roof of buildings is a good place to install the systems, if inclination and orientation are right and if the roof is capable of carrying the weight of the system.

On actual installation the quality of piping is very important, notably to avoid airlocks in the system through reverse gradients in absorbers or piping, especially with thermosyphon systems. Proper connections and closings should prevent future leaks in the system and insulation of piping should minimize energy losses.

Solar water heaters are often said to be maintenance free. In most instances this will not be the case however, especially if a system is to have a long life-time. Firstly the transparent cover of the collectors has to be cleaned regularly of dirt that might lower transmission of solar radiation. The same is true for condense on the inside of the covers. In direct systems dirty, oxygenous, calcareous or nutrient water may cause clogging up of piping, and corrosion or bio-fouling. These need therefore to be regularly flushed. Leaks in panels, tubes or connections might occur and have to be repaired. The (electric) back-up system has to be checked every once in a while on whether system and thermostat are working properly. For systems with sacrificial anodes, these anodes have to be replaced every 2 to 5 years. Indirect systems generally need replacement of the circulation fluid every few years. Forced circulation systems need maintenance of the pumps and controls. If well designed and installed these maintenance requirements will not be very demanding, but they need to be performed.

3.7. Economics of solar water heating

Economic competition of solar water heaters with conventional systems is crucial to the diffusion; as described in paragraph 3.1., the ups and downs in the development of solar water heating markets are clearly linked to the development of energy prices and therefore to economic competitiveness. Hence, to assess the possibilities of diffusing solar water heaters a micro-economic cost comparison with competing technologies is necessary. Several methods exist to do such comparisons; in this report two will be used: the simple pay-back period and the annuities method.

For both methods figures are necessary on investment and yearly recurring costs of competing systems. First an estimation of the hot water demand for an average customer should be made, followed by calculations on the type and size of system necessary to meet these demands with the different competing technologies. Preferably prices and sizes of locally available systems should be used. If such figures are not available estimations with world market prices can be made[13]. Yearly recurring costs include fuel costs and operation, maintenance and repair costs[14].

A simple pay-back period involves the calculation of the number of years necessary to win back the additional investment in a solar system, by the savings on yearly recurring costs. This method is straightforward and widely used, but has a few disadvantages. In the first place it does not allow inclusion of different life-times in calculations. In the second place no costs for capital is included. Especially if pay-back periods grow more than two years, the costs of capital should be taken into account. This is especially important for solar systems, because the costs for solar water heating technologies are mainly made up of investment costs.

To be able to include capital costs the annuities-method is used. This method is extensively discussed in Oelert (1993): yearly investment (capital), fuel and operating costs are calculated over the life-time of the competing systems. Fuel and operating costs are supposed to be yearly keeping up with inflation and therefore remain constant in real terms. Capital costs are reflected in a discount rate. The choice of this discount rate is at the same time very important and debatable; important, because a slight change in the discount rate will result in a large impact on the annual costs of solar systems; debatable because the actual costs of capital are difficult to assess and might be different for different socio-economic groups: more well-to-do households and organisations will generally have easier access to capital at lower costs than poorer socio-economic groups. This is particularly true for developing countries, where capital is generally scarce and expensive. Oelert argues to use a discount rate that is equal to the real interest rate, i.e. the interest rate paid on a medium-term loan at a bank, corrected for yearly inflation. For further details on both methods see appendix I.

---

13 World market prices for solar water heaters lie at around 150 to 170 US$ per m^2. To this should be added costs of freight, import and sales taxes and cost of installation (up to 10 to 20% of the costs of a solar water heating system) minus subsidies and tax deductions. In total this can double to triple the price per m^2.

14 O&M costs of 1.5% of initial investment are used for solar water heaters and 5% for conventional systems reflecting relatively lower O&M costs of solar systems (Oelert, 1993).

Chapter 4 Research framework and prior experiences

In chapter 2 and 3 theories on diffusion and solar water heating technology were described. In this chapter these theoretical insights will be used to create a framework for the case-study of solar water heating in Tanzania. This will be described in paragraph 4.1. In paragraph 4.2. some experiences of earlier research on solar water heaters will be described. Paragraph 4.3. describes experiences with the diffusion of solar water heaters in Kenya - a pre-study done with the framework of paragraph 4.1.

4.1. Research framework

To start building the framework for the actual field research, the original research question has to be taken in mind: 'What are the opportunities and constraints for the diffusion and local production of solar water heaters in Tanzania? What role could TIRDO play in the diffusion process?'

To be able to identify, classify and analyze the opportunities and constraints, we go back to the theories. We defined diffusion as 'the process by which an innovation is communicated through certain channels over time among the members of a social system.' Rogers c.s. focused diffusion research mainly on the (potential) adopters and their social system. Brown c.s., however, supplemented this with research on the diffusion agencies and the diffusion system. The advantage of integrating both approaches, is that the categories can be seen as influencing each other. Clearly the demand for solar water heaters will influence the decisions of suppliers and other institutions involved. Actions of suppliers will influence the objective and subjective attributes of solar water heaters. Objective attributes - such as pricing and reliability - are mostly related to the hardware of the technology, while the subjective attributes - such as information, image, etc. - are more related to the users (demand); and these attributes will be described as such. Opportunities and constraints can then be within the system or in its environment. As described in paragraph 2.2.4. this contains elements of the physical as well as the institutional environment. Within the system itself opportunities and constraints can be classified under supply, demand and technology. Therefore the framework, see figure 4.1., will consist of four groups of opportunities and constraints, concerning:

- physical and institutional environment;
- demand;
- the solar water heating technology;
- supply;

It is expected that the diffusion system in the cases to be studied will be of a decentralised nature (small-scale users and suppliers), many organisations will have to be studied. Therefore it is not possible to study all factors mentioned in theory and choices have to be made. In line with Brown, it is believed that the supply infrastructure determines availability and accessibility of innovations especially in the initial stages of market penetration, the focus in this study is on the supply and environmental side.

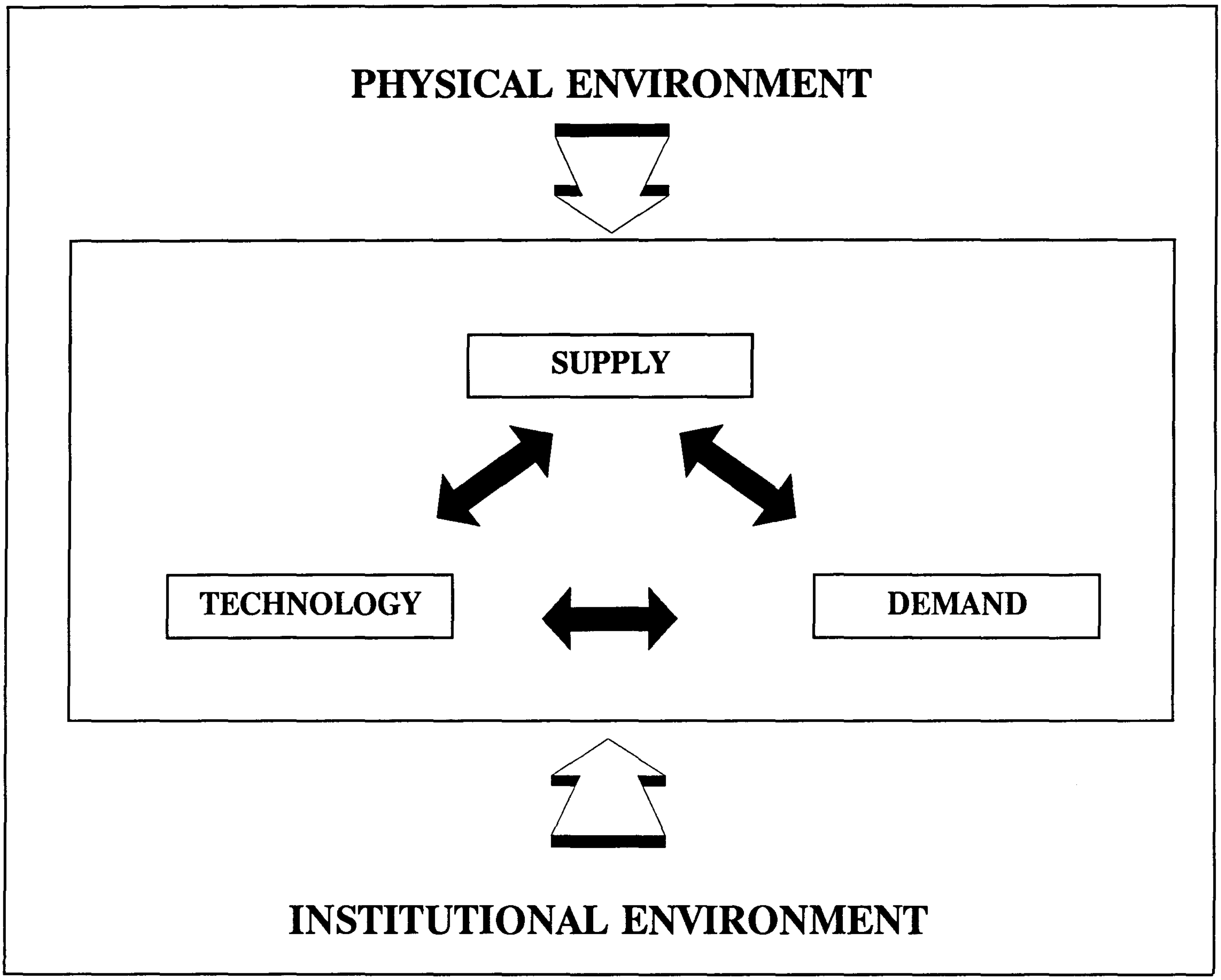


Fig 4.1. Framework for the diffusion process of a technological innovation

Because diffusion is defined as a communication process, particular importance is given to the role of information in the development of the diffusion system. Many of the interactions between suppliers, adopters and (other) institutions involve information exchange: information on technology (designs, efficiency, quality, reliability), on radiation data. Government institutions require information to design, monitor and adapt policies. R&D organisations need information on possible markets and suppliers, on possible designs, on practical experiences and needs of suppliers and users. Diffusion agencies have to have information on demand (markets), on technology, on policies, on competitors, etc. to reduce risks in decision-making on which strategies to follow. Potential adopters need information on the possibilities of solar water heaters, their advantages and disadvantages, on reliable suppliers. Actual adopters (users) need information on how to operate and maintain their systems. Diffusion researchers try to collect information on all these aspects and on the role of information itself. In short: information plays a vital role in (studying) the diffusion process.

Environment

As was described in chapter 2, institutions and elements in the environment of a diffusion system can have a large influence, shaping opportunities and constraints for the diffusion of innovations.

With solar water heaters, the **physical environment**, is of particular importance. The most important element of this is of course the amount of **solar radiation**, since this in large part determines the useful energy gain. The seasonal variation in solar radiation influences the reliability of the hot water supply (particularly for solar water heating systems without auxiliary heating). Ambient temperatures influence the demand for hot water in the area and might demand the use of systems with freeze protection. Another physical influences is the wind regime with its influence on the efficiency of the solar systems. The striking quality of these physical (climatological) characteristics is that they can generally not be influenced by people; at best some (statistical) prediction can be made of their expected values. Finally a possibly influencing physical factor is the quality of the water supply, since this may influence the durability of solar systems. The quality of water supply can be influenced by people, however.

Another important part is formed by the **institutional environment**, consisting of institutions and organizations involved in R&D, promotion, education and policies relevant to the diffusion of solar water heaters. These institutional influence will be grouped in four categories described in paragraph 2.2.4.:

- economic institution, involving relevant socio-economic circumstances, notably general poverty, economic growth, capital costs (discount and interest rates), economic structure;
- government institutions and policies: this will include specific policies concerning (stimulation of) renewable energy technologies by government (related) institutions, but also other policies that influence the diffusion of solar water heaters, e.g. energy (pricing), import policies, building regulations, credit facilities;
- R&D and education, including research programs, courses, standardization, quality control, human resources;
- other institutions, notably donor organizations;

It would also be worth analysing whether between the different institutions and elements of the diffusion system, any coordination is taking place. Effectively directing the diffusion process in a desired direction will probably demand the cooperation of these different organizations involved.

Demand

Paragraph 2.1.2. described demand-side theories on diffusion. In this framework several elements concerning the users will be used from this theory. The importance of users in innovation diffusion can not be underestimated as - in most cases - it is the users who make the final adoption decision.

In the first place the **demand for hot water** is important. How much is used, by what **type of users?** Types of users will be classified according to sectors: urban or rural households, commercial institutions and industries. Different types of users will demand different amounts of hot water; and will also place different importance to the necessity and reliability of hot water; e.g. compare the hot water demand for hospitals and households. Of these types of users it is important to know, what are their **capacities:** technical and in terms of capital. Will they be able, if willing, to buy a solar water heater, and operate and maintain it or hire staff to do this? On the basis of prior research experiences (see 4.2.) it was concluded that most solar water heaters compete with conventional boiler types run on electricity or woodfuel. Many (if not most) people in developing countries do not own such a boiler, simply because they can not afford it. If they need hot water they will generally heat it on a simple stove. It is therefore reasoned that those groups of people will not be likely to be able to afford a solar water heater either. With this in mind it is chosen to concentrate research on urban households and commercial institutions, because these have proven to be the most likely markets for solar water heaters. An additional reason for the boiler-criterium is that innovation adoption is the most likely when the necessity to change behaviour is smallest, the ownership of a boiler (electric, wood or kerosene) can be regarded as an indicator of compatibility: present users of stoves for heating water are not likely to have the capacities nor the inclination to change to buying a solar water heater.

For these users it is important to know the **relative advantage** of solar water heaters as compared to alternatives (**competing technologies**). Objectively solar water heaters have certain advantages and disadvantages: they can be seen as an expensive, durable consumer good, with low operating costs. In the paragraph on solar water heating technology these advantages and disadvantages will be described. Relative advantage is a subjective concept and related to the reasons for adoption or non-adoption. These can be of financial nature, but also in the form of reliability, comfort, ease of use, appearance, status. They depend very much on the knowledge (awareness) of the (potential) adopters and on influences from their social system.

Therefore, important as a demand variable - though difficult to operationalize - is the amount of **information, knowledge or awareness** on solar water heaters, suppliers and their advantages and disadvantages. Even if a solar water heater would only have objective advantages to certain potential adopters, they have to be aware of this fact: they have to know it (information) and believe it (trust). Awareness also links the subjective aspects of solar water heaters to strategies of diffusion agencies and other institutions (see figure 2.1.). Also interesting to know is the amount of (technical) knowledge of users on solar water heaters and their capability in operating and maintaining the systems.

Solar water heating technology

When studying solar water heating technology in this report, we are interested in the objective advantages and disadvantages compared to competing technologies. In theory solar water heating systems can easily deliver large quantities of hot water in the medium temperature range of 50 to 80 °C, saving other (conventional) sources of fuel. Because of their dependence on the intermittent solar energy source, the output of hot water is not always reliable, but this can easily be remedied with an auxiliary energy source. Alternatively a system can be oversized as a stand-alone system to account for low-energy gain periods. In stand-alone mode solar water heaters are independent of additional energy infrastructure (electricity). Other advantages include: modularity and environmental sustainability. In principle the technology is well developed and low-tech: installation, maintenance and production are possible on small-scale with limited tools and skills. The initial investment in solar water heaters is high, but their operational costs are low; and in many cases solar water heaters have proven to be economically viable compared to (conventional) alternatives.

The arguments mentioned above are in theory and should be checked in actual practise in Tanzania and Kenya and this will include user (demand) and supplier aspects. Concerning the technology itself, we are interested in the **types of solar water heating systems** encountered, the type of absorber and materials used and their (theoretical) efficiencies[15]. It is also vital to know the prices - including system costs, taxes, installation and operating costs - and durability of these solar systems available and of competing technologies to be able to make a micro-economic comparison. A breakdown of the costs will make it possible to analyze the sources of cost differences. This then creates insight into the possibilities for interventions.

Furthermore we are interested in the **actual technical performance** of these systems in practise, notably concerning installation, maintenance and repair as this gives an indication of the reliability of the systems in local circumstances. Additional technical advantages and disadvantages might be observed in practise.

To be able to make comparisons, cost and performance data of the **most commonly used competing conventional technologies** should be gathered. Finally attention should be given to the reliability and infrastructure of these competing technologies.

---

15 Because in many cases the collector efficiencies are not known, let alone the actual operating efficiencies, estimations will have to be made using the variables as described in chapter 3.

Supply

The supply-side theories in paragraph 2.1.3. focus attention on the importance of characteristics of diffusion agencies and system in the diffusion process. In this framework the important elements chosen are: the **type of diffusion system** and **type of diffusion agencies and their strategies.**

The type of diffusion system is particularly important to establish the possibilities of (government) intervention in the diffusion process. The system can be centralised or decentralised, coordinated or uncoordinated. Because the diffusion process can be regarded as communication process, the role of information is regarded as large. Attention shall therefore be given to information flows within the system: between diffusion agencies, adopters and other institutions. Furthermore attention shall be given to attitudes towards cooperation and competition.

Of the diffusion agencies the amount and type involved are important. This includes size (no. of employees, turnover, profit); public or private, foreign or local ownership; type of activities and type of solar systems marketed. Furthermore it is important to know how much expertise (technical know-how, facilities and human resources) on solar water heaters these agencies have. Possibly they can acquire information and expertise at other organisations (government, R&D organisations, universities). Is use made of these possibilities?

Their strategies includes market segmentation and selection, pricing, promotional and after-sales activities (marketing, guarantees, installation, maintenance, repairs) and the development of infrastructural and organisational capacities, like set-up of a distribution network, training facilities, R&D and cooperation with other institutions.

To study the possibilities of (more) local production a quick survey will be made of **auxiliary industries** (notably metal working), availability of materials, prices, machinery, expertise.

Furthermore, for comparison with competing technologies a quick scan of the **supply infrastructure for these competing technologies** will be made.

4.2. Prior experiences

Prior studies on the diffusion of solar water heaters in developing countries (Andersson, 1984; Walubengo, 1993; Kimani, 1993) agree on the fact that there is serious potential for solar water heaters in Sub-Saharan Africa, but that up to now markets are small. Several factors are mentioned:

- relatively low electricity costs;
- lack of trust and adequate information on the part of the consumer; in general: lack of public awareness;
- poor marketing;
- poor after-sales service due to high costs and lack of technical expertise;
- lack of standards in construction and performance and codes of practise;
- confinement of the market to urban middle- and high-income households due to high investment costs (general level of poverty);
- high overhead costs and monopolization due to small markets and number of companies involved;
- lack of credit facilities;
- lack of funds for R&D and diffusion;

Walubengo mentions that little government and donor attention (and funds) is given to RETs and solar water heaters in particular. More attention goes to large-scale conventional energy projects, because development is focused at imitation of western life-styles. If funds are accredited to RETs, many projects are not user-driven: R&D institutions develop technologies that are not suited for needs of the target groups and little attention is given to the diffusion stage. There is also a lack of focus in R&D activities, because too many RETs are developed at the same time. This is partly due to donor driven financial support. He concludes with:
' In those countries where RETs have been successfully disseminated, the governments have played a minor role. Where governments have tried to play a major role, dissemination has not been carried out successfully. This contradictory situation is caused by the high-handed manner in which governments intervene.'

One of the countries where solar water heaters have been disseminated successfully is Kenya, the subject of paragraph 4.3.

4.3. Experiences with solar water heaters in Kenya

4.3.1. Introduction

In the initial research stage of the diffusion of solar water heaters in Tanzania, information proved difficult to obtain. To be able to gather more information and make a case comparison possible, a sort of pre-study was done in Kenya. The bases for this study were economic literature (EIU, 1995) and secondary literature (Hankins, Rioba, Karekezi), supplemented with information from visits and semi-structured interviews with resource persons, suppliers and users (see appendix). Because time and financial restraints allowed for only a two-week visit to Kenya, the number of visits and interviews in Kenya is more limited than in Tanzania and limited to the Nairobi area. Description of the Kenya study will therefore be more global, mainly based on qualitative data. Still a reasonable picture of the development and diffusion of solar water heaters in Kenya is achieved. Lessons from this case can hopefully included in the Tanzanian experience.

4.3.2. Physical and institutional environment

Kenya has a population of about 25 million people with a rapid growth rate of 3.5% per annum. Only a third of the land is arable and about 75% of the rural population live on the high potential land (Karekezi 1994). For African standards Kenya has a diverse economy, with agriculture still dominant accounting for about 30% of GDP (EIU 1994/5). It has a relatively well developed private industrial sector, a high investment level (15% in a poor year) and a large export sector. GDP per head is about twice that of Tanzania and Uganda, though this gap is narrowing. After a real economic growth of more than 4% from the mid-1980's-1990, the period of 1991-1993 saw a sharp slowdown of economic growth from which the Kenyan economy is still recovering.

Kenya is endowed with abundant solar radiation, amounting to a yearly average of 5.5 kWh/m2.day for Kenya; while for Nairobi the annual average is 5,29 kWh/m2.day (Andersson, 1984). In some of the arid regions this increases to 6 kWh/m2.day. Unfortunately in the major maize, coffee and tea growing areas, where the bulk of Kenya's rural population lives, the average radiation drops to 4 kWh/m2.day in the 3-month cloudy season (USAID, 1990). The solar resource is being trapped by photovoltaic (PV) as well as solar water heating technologies. Both are the basis for a well developed private business sector. In this report the main focus will be on solar water heating, though many of the companies in this field also do PV. [16]

Kenya has no exploitable resources of oil, gas or coal. It is heavily dependent on oil imports (taking up over 11% of foreign exchange reserves in 1990, Karekezi 1994). The major local energy resources are woodfuel, hydro-power, geothermal , wind and solar. The Kenya Power & Lighting Company has a monopoly on the generation and distribution of grid electricity. It gets 80% of the electricity from hydropower, 8% from

16 For a thorough description of the PV-sector in Kenya refer to Hankins, 1994.

geothermal, 4% from (fossil fuel) thermal generation and 8% is imported from Uganda (KP&LC, 1995). KP&LC also runs 2 hybrid wind-diesel generating plants. At present Kenya is faced with an electric generating capacity shortage, which is likely to increase in the coming years (East African, 17 - 23 July). KP&LC would be one of the first ones to notice the widespread use of solar water heaters, since the most used alternative is electric water heating. The World Bank estimated in 1984 that around 64 GWh of electricity could be saved if all electric heaters in Kenya would be replaced by solar water heaters (Andersson, 1984). However, the company shows no interest in solar water heating equipment (nor in PV for rural electrification as a matter of fact), deeming their capacity too small. However KP&LC does control several thousand electric heaters in Kenya by 'ripple control', switching them on only in off-peak hours, thereby saving peak generating capacity. In exchange they charge a lower electricity rate (4,05 kshs per kWh instead of 4,3 kshs for domestic use and 4,35 kshs per kWh for commercial use).

The ministry of Energy (established in 1979) is responsible for energy policy formulation and implementation, management of the entire energy sector and for development and exploitation of renewable energy sources and energy conservation. The engineering division is involved in the promotion of solar energy (Karekezi, 1994), but their activities give very little support to the diffusion of solar technologies. In 1981 the government published a set of guidelines for solar water heating in an attempt to regulate the market, but these guidelines were not binding and no follow-up was given. No government standards exist for solar water heating, except the standards that exist on electric equipment and on water tanks (Kenya Bureau of Standards). No special credit facilities exist for solar water heating. What the government (and parastatals) did do in the 1980s was have solar water heaters installed in several government finance housing projects. No exact figures are available, but more than 1000 solar water heaters must have been installed this way, considerably stimulating the local market.

Import duties and sales taxes (VAT) also affect the sales of solar water heaters. A certain unclarity exists on the import duties on complete solar water heaters: tariffs from 10 to 20% were mentioned by different people interviewed. 20 % seems the most likely. Sales tax is set at 15% (formerly 18%). Complaints are that import tariffs on the major components of solar water heaters (like absorbers, pipes and fins) are higher: tariffs of 20 to 35% are mentioned. Many solar water heaters are installed in donor and missionary projects, which are exempted of import duties and sales tax. This of course favours the investment in solar water heating equipment, since investment in equipment makes up a much larger share of costs of solar water heating than conventional water heating. It also favours import as compared to local production or assembly however.

Other institutions involved

In 1985 a project was to be initiated with the help of the German donor organization GTZ-SEP (Gemeinschaft fur Technische Zusammenarbeit, Special Energy Program) and Kenya Industrial Estates Ltd. (KIE) to develop a local solar water heater. It was not possible to confirm this however and none of the persons interviewed had heard about it. GTZ is also supposed to have been involved in giving training courses to Kenyan and Tanzanian artisans in cooperation with the company Italproducts, Nairobi (see list of people interviewed). The results of these trainings apparently have not been durable. As far as known no follow-up was given.

The Kenyatta University has a department of Appropriate Technology. There an undergraduate and a MSc. course are given in renewable energy technologies, also high-lighting solar technologies. The department has plans to develop a low cost solar water heater for local production in East Africa. This has not materialized yet however. There was also a project on solar water heaters for Agricultural Engineering students of Egerton University (Karekezi, 1994). Companies get their personnel from technical colleges: plumbers and electricians and give them an on-the-job training. The lack of well trained personnel is often mentioned as a problem by companies involved. The people sizing and designing systems generally have an engineering background.

4.3.3. Demand

The main markets for solar water heaters are with households in the middle and high income groups and institutions (hotels, hospitals, missions, schools, etc.). Many of these seem to prefer imported solar water heaters to locally produced ones. Probably partly for reasons of status and image, partly because several local solar water heaters have proven of low quality. The companies that import and those that assemble locally also provide better after-sales and put more effort in marketing.

Most solar water heaters seem to be bought for cost-saving purposes, but in many cases no cost comparison of investment and savings is made. In appendix I such a comparison is made for an average urban household in Kenya, proving that solar water heaters are - in some cases - economically more attractive than electric boilers. Curious, however, is that the Solahart boiler (representing the expensive imported boiler category) proves to be the most expensive option, while the sales of these boilers seems to be considerable. Additional reasons for buying solar water heaters are: unreliability of electricity supply or in some cases unavailability of electricity or other adequate energy supply (f.i. in wildlife lodges). For donor organizations and some tourist resorts environmental concern seems to be an important reason.

Most of the solar water heaters are sold with electric back-up for cloudy periods. The total acclaimed electricity savings vary from 50 to 90%. The main competing water heating technology is the conventional electric boiler. For large institutions diesel and light fuel oil boilers also seem to be an attractive option and for rural areas, where no electricity is available, woodfuel boilers are an alternative. However, during the short period in Kenya no quotation for these boilers could be obtained. A problem with woodfuel boilers is that the price of woodfuel can vary a lot per region and season.

4.3.4. Solar water heating technology

The main part of the solar water heaters installed in Kenya are of the direct, thermosyphon type, with a separate tank with electric back-up heating. The last few years several imported, indirect systems have come on the market however, and they seem to be selling well. They have the advantage that their performance is not affected by 'hard', corrosive water. Such water is especially found in the coastal regions and in places where they use borehole water, like lodges. For larger, institutional projects pumped systems are sometimes used, but in many cases separate, thermosyphon systems are used (creating a sort of decentralized hot water supply). The smaller, thermosyphon systems come in standard sizes: mostly 120 and 180 litre, but also 300 litre. At least one company, TOTAL Solar, is capable of providing solar water heaters with woodfuel back-up for remote areas. These are not often sold however, since in those cases the systems often go without back-up.

4.3.4. Supply

At present many companies in Kenya are involved in the distribution, installation and maintenance of solar water heaters. Among the 8 companies visited (all in Nairobi, see appendix II), two are involved in local production (Italproducts and Alpa Nguvu), three are involved in local assembly (Total Solar, Solatec and Solar World import the main components); and three are involved in import (Kenital, Wilken and Digitel). Several other companies are supposed to be active in solar water heating, but these couldn't be visited through lack of time (see appendix). Because of the many players involved none of the companies does solar water heating as a sole business activity. The most frequent other activity is solar photovoltaics, followed by telecommunication. All companies are small to medium-sized: maximum of about 30 employees. The companies seem to address different markets, as will be described.

The three importing companies have the most expensive products: indirect solar water heating systems with a top tank in standard sizes of 180 and 300 litre, a back-up electric heater and one to three panels. They do little to no large, institutional systems. Wilken (Solahart) has done one such system, but design and sizing is left to the Solahart office for Europe and Africa in The Netherlands. They mainly serve the 'rich' market of tourist hotels and resorts, wildlife lodges, embassies, etc. They do all installations themselves and give extensive aftersales services. Especially Wilken markets their products aggressively. Although affected by the decline in the market, they seem more optimistic about the future of solar water heating in Kenya. Up to a few years ago Kenital sold solar water heaters locally produced by Italproducts, but - though a lot cheaper than the imported ones - the demand for these systems was too low. Now Kenital imports systems from Greece (Megasun). Wilken and Digitel import their systems from Australia (Solahart and Edwards respectively)

Total Solar and Solatec are the largest solar water heating companies in Kenya, both in the business since 1979, starting with import, later switching to local assembly. Total Solar has a licence agreement with Beasley, Australia and Solatec imports its solar components from Thermatool, Canada. Both companies have done many larger, institutional systems, but with the decline in the market they also have had to concentrate more on smaller systems for private households. By now Total Solar sells more panels to private persons and individual plumbers doing the installation by themselves. The complaint is that many of these systems are badly installed, thereby spoiling the market. Solatec has seen itself forced to also start importing complete systems from the same Canadian company at demands of clients, notably for indirect and pumped systems.

Alpa Nguvu and Italproducts seem to mainly sell to the rural market: missions and hospitals. Alpa Nguvu does solar water heating and photovoltaic solar systems. It gets part of its solar absorbers and in some cases complete panels from Italproducts. These products are made of galvanized steel, which is more easily corroded than the copper and stainless steel of other panels. Alpa Nguvu also produces a solar water heater made of copper, but with a bad thermal connection, probably leading to a low efficiency of the system. This design is certainly a lot different from the one they mention in their product brochures, which has been tested in Italy. Italproducts is a metal-working company with products varying from pots and pans to water storage tanks and boilers. It has also been involved in giving training courses to Kenyan and Tanzanian artisans, in cooperation with the German donor agency GTZ. The results of these courses are unknown.

4.3.5. Development of the diffusion system: opportunities and constraints

Already in the 1960s and 1970s pioneers were building and importing solar water heaters in Kenya: mainly imported from Israel and Australia for tourist hotels/resorts at the coast and lodges in wildparks. At the end of the 1970s several companies, especially TOTAL Solar, then owned by the American oil company TOTAL, started setting up a distribution network in Kenya and training technicians. This is in the period of the second oil crisis with rising energy prices. In 1981 the United Nations Energy Conference in Nairobi raised interest in renewable energies among donors, the Kenyan government, consumers and the private sector. The sales of solar water heaters started expanding rapidly. Several companies started local assembly of solar water heaters (under license and components imported) and some started local production. Sales were mainly to hotels, hospitals, missions, schools and other institutions. Solar water heaters included in large donor and government financed housing projects helped to establish the market. One of these projects was the BuruBuru estate in Nairobi. In this government financed housing estate 1000 solar water heaters were installed in 1985. Unfortunately many of these water heaters failed after a short period. In 1986 an estimated 14,000 to 18,000 m2 of solar water heaters were installed (Hankins, 1987). The market for solar water heaters kept growing fast up to the 1990s. Many companies started getting involved, some of them of lesser quality, leading to complaints they are spoiling the solar water heating market. At the end of the 1980s an attempt was made by several companies to create a Kenyan Solar Industries Association. This never materialized however. From 1991/1992 on, with the economic depression and devaluation of the Kenyan shilling, prices of solar water heaters rose sharply (threefolded between 1990 and 1995). The market for solar water heaters seems to have been contracting since, forcing all companies to diversify their activities. Especially the companies with local production or assembly facilities seem to have been hard hit. From mainly doing large, institutional and housing projects, the companies also have to start giving more attention to individual sales to private households, mainly in the middle and high income brackets in urban areas. By 1995 the estimated area of solar water heating panels installed exceeds 30,000 m2. These facts on the diffusion of solar water heaters in Kenya are summarized in table 4.2.

The strength of the Kenyan case of solar water heater diffusion is that it led to a large penetration of solar water heaters with limited government support. In essence the diffusion of solar water heaters in Kenya developed through private initiative without coordination. The system can therefore be characterised as a decentralised, uncoordinated system. The most effective government incentive was the stimulation of the market in the 1980s by installing solar water heaters on government financed housing projects. Especially the high energy prices and the attention for environment in the beginning of the 1980s created a good climate for the growth of a market for solar water heaters. Of course the solar and climatological conditions in Kenya offer favourable opportunities to the use of solar systems, especially in the central highlands - including the densely populated areas of Nairobi. Constraints lie mainly in the disincentives for solar water heating systems due to the high import and sales taxes on systems and components. The main markets are with urban households and institution, competing with electric boilers. The dependence on imported collectors and components has trebled the prices of solar water heaters (in kshs) since 1990, while electricity prices have grown much less, making solar water heaters less economically attractive, leading to a decline in the market.

Additionally no quality control or efficiency testing exists in Kenya. This leads to unclarity about the energy and cost savings capable with solar water heaters. Lack of control also favours the existence of bad products and installations on the market, damaging the image of solar water heaters. It seems as if especially local products suffer from this bad image, since they don't have a brand name or international test to promote their product. Lack of support also affects local production negatively. Little local R&D is done and little contact between this and solar water heating companies seems to exist. Local production is also hampered by: expensive raw materials, low production volume and little money to invest in R&D, marketing and distribution.

Also companies complain of the difficulty in finding skilled personnel. Many companies started to explore the solar water heating market and invested in training people for installation and maintenance themselves. The competition also leads to attention for marketing, and after-sales services (including instruction upon installation and decent maintenance). The advantage of local assembly is that it gives access to foreign technology and R&D, while still maintaining a component of local production. The existence of this supply infrastructure also stimulates the exploration of new and diverse markets and products, despite the economic decline in the 1990s.

period (years)	institutional environment	technologies used	supply	demand
- 1980		? presumably direct thermosyphon systems	small amount of individuals involved in local production and import	tourist hotels and lodges
1980-85	-1981 UNEP conference - government guidelines - rising energy prices	separated, direct, thermosyphon systems	rapid expansion of companies, mainly: import: - TOTAL solar - Solatec local production: - Italproducts - Alpa Nguvu	hotels, lodges, missions, hospitals
1985-90	- GTZ-SEP - economic growth	introduction indirect systems	local assembly - TOTAL solar - SOLATEC new importers -Wilken	rapid growth of the market; sales also to private households and (government) housing estates in 1986 14,000 - 18,000 m² installed
1990-	economic decline 1991-1993	many indirect systems sold; introduction integrated systems with electric back-up	new importers: - Digitel - Kenital	contraction of the market; less large institutional projects; (relatively) more households 1995: ca. 30,000 m² installed

Table 4.1 Summary diffusion of solar water heaters in Kenya

Chapter 5 Solar water heating in Tanzania

5.1. Introduction

In this chapter the diffusion system of solar water heaters in Tanzania is described using the framework of chapter 4. Data is gathered using economic and secondary literature (EIU, 1994; Andersson, 1984; TIRDO, 1995); supplemented with semi-structured interviews, field visits and inspection of systems in the field. At 16 institutions interviews were held covering the range from energy ministry to R&D; from education to electricity supply; from NGO to donor organisation. These interviews provided the basis for paragraph 5.2. on institutional and physical environment. 15 companies somehow involved or interested in solar water heating or competing technologies were visited and interviews were held to gather information on supply and technology. With their information on the main types of users of solar water heaters, a selection of users was made, visited and interviewed. On 17 sights systems were inspected and users interviewed on reasons for and experiences with using a solar system. It proved difficult to gather adequate data on hot water demand, efficiencies, etc. In those cases estimations have been made on the basis of literature (Streib, Bacibo, Andersson). Due to limitations in time and finance, the research concentrated itself on Arusha and Dar es Salaam, with a detour to the Mbeya region. These areas were selected because of concentration of activities in the field of solar water heating and potential markets. All the organisations visited are listed in appendix IV.

5.2. Physical and institutional environment

Tanzania, made up of the mainland Tanganyika and a number of off-shore islands including Zanzibar, Pemba and Mafia, lies between 1 and 11 ° South latitude. It has a population of about 27.4 million people with an annual growth of ca. 2.8% (mid-1994 estimate, EIU, 1994) on an area of 945087 km^2. It is one of the least populated countries in Africa. About 85% of the of the population lives in rural areas (BoS, 1994). In the rural areas the largest population densities occur on the fertile lower slopes of Mt Kilimanjaro and on the shores of Lake Malawi. In general the upland areas have relatively high population densities as compared to the lower areas. Dar es Salaam is the main port, the dominant industrial centre and the focus of government and commercial activity. Arusha has also been growing rapidly in recent years, partly because of its importance to Tourism.

The per capita income in Tanzania was around 100 US$ in 1993, although it must be added that large parts of the (rural) population gain their livelihood outside the monetary economy, especially through subsistence farming. Agriculture is still the most important sector of the economy , with over 61% of the GDP (1992) and the largest foreign exchange earner. Tourism is at present the largest growth sector and second largest foreign exchange earner. Since the mid-1980s Tanzania has had to leave its socialist (Ujamaa) development path, forced by economic setbacks. It has adopted Economic Recovery and Structural Adjustment Plans as suggested by the IMF, leading to start of privatization of parastatals, the decrease of civil service and many social services (a.o. education and health care). The 1986-1992 period saw an average growth rate of GDP of 4.1.%. Economic growth prospects are mixed: with rising inflation and a hesitant donor community. For 1995 an economic growth of 3.5% is expected (EIU, 1994). In the future much will depend on the outcome of the elections, the new government policies and reactions of the donor community.

Tanzania includes a wide variety of land forms and climates. The coastal region enjoys a tropical climate, while more inland the climate is semi-temperate due to the elevation above sea-level - especially in the northern and southern highlands. In Dar es Salaam, at the coast, mean minimum and maximum temperatures of 23 and 32 °C are recorded in the hottest month- January - while these are 18 and 30 °C respectively in the coldest months of July and August. Because of the high temperatures and humidity in the coastal areas, the demand for hot water - f.i. to take showers - will generally be lower - especially by individual households. In the higher situated areas, that are colder, demand for hot water will generally be higher. For a town in the northern highlands like Arusha (altitude 1387 meters), these values are 14 and 28 °C in the hottest month, February, and 12 and 22 °C for the coldest month of July respectively. Freezing is not a problem in most areas of the country (except possibly above 2500-3000 meters). For much of the country most of the rain falls in one rainy season - December-May - though two peaks of rainfall in October-November and April-May are found in some areas. Naturally solar radiation is lower in the rainy period(s) than in the dry period(s).

The mean yearly average daily solar radiation for Tanzania is reported to be aroun 4.6 kWh/m^2.day (various sources: a.o. Mwandosya, 1993). For comparison: this is about twice the amount of solar radiation that North-Western Europe receives. For Dar es Salaam this would be 4.97 kWh/m^2.day (EAC, 1975), with a large variation of mean monthly average daily radiation of 4.05 kWh/m^2.day in the month of April; up to 5.72 kWh/m^2.day. In Arusha this increases up to a yearly average of 5.38 kWh/m^2.day; and there is even recordings of up to 6.82 kWh/m^2.day in Mbarali near Mbeya in the Southern highlands (1052 meter, EAC, 1975), while this drops to 4.41 kWh/m^2.day in Bukoba (1137 meter, EAC, 1975) at lake Victoria. It can be safely concluded that Tanzania is endowed with a favourable solar energy source.

Water quality in some areas (e.g. in the Arusha/Moshi area), especially borehole water but also some publicly supplied water, is of low quality with a high total hardness value and a lot of mud contents, depending upon the season (e.g. see Tarimo, 1995). Low water quality easily affects the performance and life-time of solar water heaters and this will - in turn - affect the decision on the type of solar water heater to be installed. If water quality in an area is very low, it might be best to choose for an indirect instead of a direct system. No systematic data could be found on water quality through Tanzania, however.

5.1.1. Overview of main energy issues and energy policies

Biomass is - with more than 94% of the energy supply - by far the most important energy source in Tanzania. In general Tanzania is a country with sufficient biomass supply, but localized deforestation problems do occur, mainly in the arid and semi-arid regions of Shinyanga, Mwanza, Tabora, and Arusha (Mwandosya, 1993). Also around large urban areas, forests are being depleted faster than regeneration can occur.

	fuelwood	charcoal	coal	oil products	electricity	total
Supply						
production	695.6		0.7		5.9	702.2
imports			0.6	45.6		46.2
exports						
stock exch.			0.3	(2.1)		(1.8)
total supply available	**695.6**		**1.6**	**43.5**	**5.9**	**746.6**
Conversion						
charcoal prod.	(15.7)	15.7				0
electr. generation				(1.0)	1.0	0
losses	(141.3)		(0.5)	(3.9)	(1.0)	(146.7)
bunker/exports				(2.3)	(0.5)	(2.8)
net available for consumption	**538.6**	**15.7**	**1.1**	**36.4**	**5.4**	**597.2**
Consumption						
industry	43.1	1.2	1.1	7.0	0.9	53.3
commercial	10.8	0.3		0.1	1.3	12.5
transport				23.1		23.1
households	474.0	13.8		4.3	1.6	493.7
other	10.8	0.3		2.3	1.6	15.0

Table 5.1. Energy balance Tanzania mainland 1992 in PJ ($=10^{15}$J; source: v.d.Vleuten, 1995)

* figures between brackets have a negative value

** figures in the row 'total supply available' represent primary resources available; many of these resources are processed ('converted') before being made available for consumption, especially from fuelwood to charcoal and from oil to electricity. The conversion process also includes refining and transportation losses.

Tanzania also has a large resource of hydro-power of which currently around 10% is used for electricity generation (MWEM, 1992). Around 80% of electricity demand is met by hydro-power, the remainder being generated from diesel. Though only around 6% of the population has access to electricity and per capita electricity consumption is low, 59 kWh in 1992, this has been growing fast in the last years. Since the beginning of the 1990s Tanzania is faced with an electric capacity shortage, which has forced the Tanzania Electric Supply Company Ltd. (TANESCO) to apply rationing to most regions of Tanzania. The commissioning of new gas turbines at Ubungo power station and the expected supply of natural gas from the Songo Songo gas field under development, are supposed to remedy this problem around 1997. In the mean time plans exist to allow independent power producers in Tanzania, thereby breaking the monopoly of TANESCO. At the moment average electricity tariffs cover the long run costs of production and distribution, but cross-subsidisation from larger to smaller consumers (private households) still persists. This is supposed to be gradually finished under the electricity sector reform program agreed with the World Bank. According to the latest tariffs (June 1995) households would be paying about 45 Tshs per kWh and commercial users up to 100 Tshs. Tariffs based on long run marginal costs would amount to 60 - 70 Tshs per kWh (Tanesco, 1993). TANESCO has expressed its interest in promoting solar water heating as a means of demand side management of electricity consumption, if it can be proven to be financially viable for individual consumers.

Tanzania has other indigenous energy sources in the form of coal and natural gas. Most of these reserves are not being exploited yet, however. The gas fields at Songo Songo are currently under development and are supposed to start supplying gas to Dar es Salaam in 1997 for industrial and power generating purposes.

At present Tanzania is completely dependent on import to meet its demand for petroleum products. The transport sector is the largest consumer of oil products with around 63% of the total consumption. Import, refining and prices of oil products are controlled by the parastatal Tanzania Petroleum Development Company (TPDC). Some oil products (mainly kerosene and LPG) are being cross-subsidized at the expense of other fuels, like diesel and gasoline.

The Ministry of Water Energy and Minerals (MWEM) is responsible for the energy policies in the mainland of Tanzania[17]. Among others it controls the prices of electricity and petroleum products, through the parastatals TANESCO and TPDC respectively. In its energy policy (MWEM, 1992) it stresses the wish to make the energy consumption and supply in Tanzania more sustainable and less dependent upon imported fuels. The policy also contains a paragraph on renewable energies. It mentions a.o.:
'In order to reduce use of wood and oil for water heating purposes [..], all new community construction projects and hotels will be required to install solar water heating equipment.'
To be effectively put into effect such an obligation should be incorporated in the national building codes. The MWEM has expressed its wish to do so, following the successful example of Botswana, without giving a time-frame however.

[17] Zanzibar has its own ministry of Energy and electricity distribution company.

5.1.2. Import policies

Import taxes on solar water heating equipment are high: 20% import tax and 30% sales tax; amounting to a cumulative taxation of 56%. The same tariffs are valid for electric heating equipment, but since investment costs are a much larger part of ultimate costs for solar than for electric water heating, the high tariffs hit harder on solar water heating. the 30% sales tax is also applied to locally produced electric and solar water heaters. Fuel boilers are exempted from sales tax and only attract 20% import duties. Government projects and many donor and missionary projects are exempted from both import duties and sales tax. This, of course, favours the purchase of solar water heaters, but it also (relatively) favours import to local production.

The import taxes on raw materials for solar water heaters - especially metals like copper and aluminium - attract even higher import taxes of 30 to 40% and sales tax of 30%. Complaints are that in many cases both import duties and sales tax have to be paid on import of these materials, and again 30% sales tax on sales of the finished product (in this case the solar water a solar water heater). This double taxation is very unfavourable to local production.

Solar, electric and fuel water heating equipment manufactured within the PTA or COMESA-zone[18] attracts lower import duties: at the moment 6%, but this should be lowered to 4% in 1996, 2% in 1998, and completely abolished in 2000. The same sales taxes will hold.

In 1993 a special tariff group was created for photovoltaic solar equipment, attracting 5% import tax and no sales tax. Solar water heating equipment was not included in this tariff group, however.

5.1.3. Research and Development

All scientific research and technology development in Tanzania is monitored and coordinated by the Tanzania Commission for Science and Technology (COSTECH). It channels money from donors and the Ministry of Industries and Trade to research organizations. Among others it has financed inventarisation research into the diffusion of solar energy systems (Ngosi, 1994). Most of the scientific research in Tanzania is done by the universities and by the 4 'sister' institutions TIRDO, CAMARTEC, TEMDO and IPI. For solar water heating the activities at the University of Dar es Salaam (UDSM), CAMARTEC and TIRDO are the most important.

---

18 PTA stands for Preferential Trade Area; COMESA for Common Market for Eastern and Southern Africa. COMESA is the follow-up of the PTA, a cooperation between several countries to create a common market. These countries include Tanzania and Kenya. South Africa has a special observer status.

TIRDO

The Tanzania Industrial Research and development Organisation (TIRDO) was created in 1979 to carry out applied R&D in industrial technologies and promote transfer of the results. Among others it has a department specialized in energy research. It started a program on solar thermal systems. It already developed 2 types of solar driers and has expressed interest to do work in the field of solar water heaters for household, institutional and industrial use. It has applied to the Norwegian development organization NORAD for support to this project.

CAMARTEC/AATP

The Centre for Agricultural Mechanisation and Rural Technology (CAMARTEC) came into being in 1982 after a fusion of Arusha Appropriate Technology Project (AATP) and Tanzania Agricultural Machinery Testing Unit (TAMTU). Formerly, between 1978 and 1982, AATP had developed and manufactures a solar water heater for household and institutional purposes: a separated, direct, thermosyphon system, made according to a radiator design. Commercialization of the device never succeeded, however. By now the employees responsible for the development of this solar water heater have left CAMARTEC and none of the experience seems to have been saved. At present CAMARTEC is more involved in the development of solar cookers.

UDSM

At the University of Dar es Salaam (UDSM) mainly the engineering and physics departments are or have been involved in activities on solar water heating. In the seventies and the eighties the physics department did some research on different types of solar water heaters. This researched was stopped, however, since progress was slow and funds were lacking. There was nobody to pick up the results of the research. After that the physics department has worked on producing and studying selective absorption and transmission coatings, a.o. electrochemical deposition of black nickel, which could be used as selective absorption paint for solar water heaters.

The engineering department has also done some research on solar water heaters, but mainly in the form of graduation projects for students. A.o. they developed an integrated solar water heater with additional insulation to keep water hot over night. No attempts were made to disseminate the results. The department also gives a course in solar thermal energy systems to undergraduate students and is starting one for MSc. students in the next year.

5.1.4. Other institutions

TATEDO

The Tanzania Traditional Energy Development Organization (TATEDO) is an NGO, created in 1990, that has been successful in coordinating production and diffusion of improved charcoal stoves (Jiko Bora) in Dar es Salaam. It has written a project proposal to the Japanese donor organization (JICA) to start a project on training of local technicians in installation and local production of solar energy devices (both photovoltaic and solar water heating).

Donor organizations

Several donor organizations have contributed to individual projects in the field of solar water heating, especially instalment of solar water heaters with mission posts and hospitals. Especially the Danish donor organization DANIDA - through the Danish Missionary Council - has contributed to several of these projects. No knowledge exists of donor organizations contributing systematically to the diffusion and local production of solar water heaters in Tanzania.

BACIBO

BACIBO is a small Dutch foundation that started in 1981 to help institutions in various developing countries - especially rural hospitals, maternities and rehabilitation centres - to design, manufacture and maintain solar water heating systems. After trying several designs, they concentrated on a separated, direct, thermosyphon solar water heater. The design they chose was a zigzag or serpentine design, which is easier to produce with locally available bending and soldering tools. The absorbers are generally made of galvanized steel, since this is more readily available in rural areas in developing countries, than copper or aluminium. They held 4 training sessions in south-west Tanzania: in 1981, 1983, 1995 and 1996, in total making between 15 and 20 systems. Most systems still perform well. Contrary to expectations, however, few new systems were built by the trained technicians after BACIBO left in 1981 and 1983. BACIBO tried to stimulate permanent local production, but this was not successful; apparently because the demand was too small. Such permanent local production is not a primary goal of these training sessions, but BACIBO is interested in transferring expertise to local organisations that could stimulate small-scale local production. In Tanzania up to now no such organisations were identified. In Zaire, after training sessions, a commercial company apparently started to manufacture the systems commercially, with government subsidy.

BACIBO also designed a special tool-kit to facilitate manufacturing of the solar water heating systems. They also developed a design manual and training videos for this purpose. Remarkable - and probably reason for the partial success of their projects - is the adaptation of their system to the existing habits for hot water supply in the institutions: the solar systems resemble traditional woodfuel hot water 'towers'. The systems also have one, centrally located tapping point, which facilitates social control over the hot water use.

5.3. Demand

In Tanzania hot water between 50 and 90 °C is mainly used for bathing and laundry and consumption will be low on average in a poor country like Tanzania: priorities will generally be with other, more basic needs. The hot and humid climate in the coastal regions will suppress the demand for hot water even further. In many cases, if hot water is needed, it will be heated on an ordinary stove (woodfuel, charcoal, electric or otherwise); no separate device being used for bathing water. SWHs will generally not compete in the same market as these stoves, but in the market for electric boilers. These are mainly owned by the more affluent - middle and high-income urban households and institutions.

The first step to assess hot water demand by selected user types, causes problems: no exact figures on hot water consumption in Tanzanian households could be found and even less on patterns or time of consumption. General and vague estimations claim that 5 to 8% of total domestic energy in developing countries is used for low temperature water heating (Kristoferson, 1988): this would amount to 7 to 11 GWh per year, heating ca. 10 liters of hot water p.p. per day. Of course hot water consumption in middle and high income, urban households would be higher than in poor, rural households. Andersson (1984) mentions an average of 4200 kWh per year of electricity use for water heating in urban households in Kenya, which amounts to 150 to 200 litres of hot water per day per household. He also quotes literature figures in the order of 25 to 30 liters of hot water per day per person in countries like Zambia, Mauritius and Liberia. Based on these figures the average daily hot water consumption for an average urban Tanzanian household, using a boiler type water heating system[19], is estimated at 150 liters (60°C). The main conventional technology used in such urban households in Tanzania are electric water heaters. In rural - unelectrified - households this will often be woodfuel water heaters (or stoves). Assessment of the financial costs of solar systems compared to such woodfuel systems is made problematic by the large variation per region of woodfuel prices. In those cases affordability of the investment, ease of use and possibly status arguments will probably be more important for the decision to buy a SWH, but this could not be verified in the research.

Another Tanzanian sector using large amounts of hot water is the commercial/institutional sector: hotels, hospitals, schools, offices, missions, etc. Many such institutions have to provide hot water to meet their clients' demands. Again no exact data on hot water consumption specific for Tanzania could be found. Estimates for hotels, based upon experience of solar water heating firms in Arusha and Nairobi, are that 30 to 50 litres would be used per person per day. The most used conventional alternative seems to be electric water heating, if electricity is available. Although some institutions are quite large, they mainly seem to use small (up to 500 litre) electric boilers to serve a few rooms at a time; the most likely reason for this being that larger size electric boilers seem difficult to acquire in Tanzania. Such small size boilers could be easily replaced by standard 180 to 300 litre SWHs on the market in Tanzania. Very large institutions run imported (steam) boiler systems on industrial diesel oil (IDO). In rural areas institutions might use woodfuel water heaters. Again financial comparison is made difficult by the variation in woodfuel prices; and ease of use and the will to conserve woodfuel might be more important reasons. In

19 As explained, these will generally be the more affluent households.

some cases where electricity is not (regularly) available - like lodges and some hotels visited in Arusha and Dar es Salaam - electric water heaters are used and run on electricity generated with small diesel generators. The price per kWh for such generated electricity is generally very high (minimum estimate would be 120 Tshs per kWh, based upon a 220 kVA diesel generator (v.d.Vleuten, 1995)).

Hot water is also used in several industries, like textiles, food processing and laundries. Another possible use would be the pre-heating of water for boilers. Studying energy audits of industries in Tanzania (appendix V), several industries using large amounts of hot water or steam were identified - particularly in the subsectors mentioned. No exact figures on hot water use could be obtained. However, the industries covered that used large amounts of hot water, all obtained this by using large boilers run on furnace oil. Comparison of the costs per energy unit for solar heated water and the fuel savings, proved the solar option unjustifiably high, with a simple pay-back period of more than 17 years (appendix I, case 4). This corresponds with observations in literature (a.o. Dickinson, 1988). Dickinson adds that most industries would profit more from installing energy saving equipment or from co-generation than from solar. This again corresponds with the findings of industrial energy audits in Tanzania done by TIRDO: for all industries energy saving measures were identified with pay-back periods of 0 - 2 years (Tarimo, 1995). Dickinson also adds that solar systems for pre-heating feed water will conflict with boilers with large economizer sections: pre-heating the water with solar will bring the boiler efficiency down. On top of that, the low energy density of solar radiation will demand very large solar collector surfaces, possibly causing problems in urbanized areas. Therefore it should not be a surprise that no SWHs have been found to be used in the industrial sector in Tanzania.

Most of the SWHs found in Tanzania at the moment are used in the urban commercial/institutional sector. Many of the systems installed in hospitals and missions have been donor financed (appendix II). The available information is too little to draw definitive conclusions, but indications are that a geographical concentration of solar systems occurs in the Arusha-area. This is probably be due to the availability of supply infrastructure both in Arusha and from Nairobi.

The main reasons mentioned for using a SWH are cost savings (11 out of 17 users). In several cases (6 out of 17) the unavailability or unreliability of conventional energy sources (electricity or woodfuel) was mentioned as motivation for investing in solar systems. In one case (the donor organisation USAID) environmental reasons were mentioned as relevant reasons. Environmental reasons were also mentioned by other donor organisation (interviewed as institutions) to choose for SWHs in projects (e.g. DANIDA and SIDA). Reasons for not buying were mainly due to high investment costs. Many of the users interviewed had problems with their SWHs (6 out of 18). Studying appendix IV would lead to similar conclusions. The existence of so many broken down SWHs should have a negative influence on the image of SWHs. This could not be corroborated in the research, however.

The cost comparisons with conventional water heating in appendix I show that SWHs are mainly financially attractive for institutions with a pay-back period of 2.5 to 3.1 years for a local and imported SWH respectively. Because pay-back periods are more than 2 years, comparison of annuity costs is needed to evaluate the influence of capital costs and life-times. For urban institutions in Tanzania annuity costs of both imported and local SWHs prove to be more than 1.5 times lower than for electric water heating. For urban as well as rural households SWHs prove more expensive than conventional water heating (electric and woodfuel respectively.

Institutions are more likely to purchase SWHs for another reason too: institutions will generally have more easy access to capital to invest in expensive solar water heating equipment. Because institutions seem the most viable market for solar water heaters, an estimation of this market would be interesting. Tanzania has approximately 3555 clinics, 7200 churches and missions[20] and 250 hotels (with tariffs of more than 1000Tshs per bed-night)[21] with around 13000 beds. Since tourism is a high growth sector and major foreign exchange earner, some calculations will be made for this sub-sector. At around 35 liters of hot water per bed a day[22], hot water demand for these hotels would be more than 7 GWh per year. If all of this demand was to be met with solar water heaters more than 8000 m^2 of collector area would be needed. Although the assumptions are optimist by far, this gives an impression of the potential of this market for solar water heaters.

Complaints by diffusion agencies (suppliers) and other people involved in SWHs are these systems are still relatively unknown in Tanzania. People associate 'solar' with photo-voltaic systems. It must be said that the availability of these systems and promotional activities (e.g. by suppliers) have remained very limited up to now. Also the knowledge on existing suppliers seems to be limited with (potential) adopters, let alone that they have knowledge on 'reliable' suppliers. Studying the list of SWHs known to have been installed in Tanzania (appendix II) suggests that most of the actual adopters are somehow more 'exposed' to western contacts: through tourists (large hotels in Arusha, Moshi and Dar es Salaam), donor organizations and missions (as financiers of projects) or government. Therefore awareness and adoption seem to be positively related to 'western contacts' or 'western orientation'.

Furthermore interviews with users and inspection of actual systems has shown that few users have any technical knowledge or expertise on the SWHs they have bought. Therefore they are generally not capable themselves to properly install and maintain these systems. This is particularly a problem when the supporting infrastructure is weak as is the case in Tanzania. This lack of technical knowledge is confirmed by the findings of the foundation BACIBO during their years of work with SWHs in Tanzania. A positive exception form a few cases of hotels and hospitals, where maintenance personnel - generally plumbers - has acquired some technical knowledge through learning-by-doing, i.e. keeping the systems running.

---

20 source: Tanzania fact sheet; from SADC NRSE Pricing and applications studies; August 1992.

21 source: Tanzania Bureau of Statistics; Bi-annual hotel statistics report; March 1995.

22 average based on experience of Kenya based solar company Total Solar.

5.4. Solar water heating technologies

In appendix II a list has been attached of SWHs found to have been installed in Tanzania. The majority of the systems were installed in the commercial/institutional sector, mostly found as many small systems (100 - 300 litre tank with up to 4 m^2 collector area). Most systems are of the separated, direct, thermosyphon type, mainly with electric immersion heaters as back-up. In the 1980s systems were imported from the USA and Israel (all direct systems). The last few years a load of indirect systems seems to have been installed, mainly imported from Australia; this might become a trend (especially because this is also observed in other countries like Kenya). These indirect systems have the advantage that they are less succeptible to damage by corrosion or clogging up and will therefore have a longer life-time. They are a lot more expensive, however.

The last few years several systems were also imported from Kenya especially in the Arusha/Moshi area, some also being installed by Nairobi based companies. The last development - no more than a year old - seems to be the introduction in Tanzania of integrated SWHs imported from Greece and South Africa - with and without electric back-up. These systems are generally easier to install and less succeptible to maintenance problems. A lower efficiency is generally a problem with these systems, however, but no technical details on the integrated SWHs available in Tanzania could be obtained.

Some systems had been locally produced: all of the separated, thermosyphon, direct type. Some were made with a snake absorber of galvanized steel as transferred by the Dutch foundation BACIBO (see paragraph 5.2.4.). Though installed mainly in 1981 and 1983, many of these systems still seem in good working condition. Several attempts have also been made to produce tubular register type SWHs (Jandu Plumbers and CAMARTEC), but these efforts were not continued when they proved economically not viable.

Many of the systems installed did not function any more after a short period or never functioned at all, particularly the imported American and Israeli systems, installed by AISCO. Many of the systems inspected, were seen to have been inadequately installation (air-locks, long uninsulated pipes). Some systems were in a bad state: heavily corroded, leaking pipes, glass broken, paint coming off. Maintenance seems to have been neglected for many of these systems. In a few cases the problems with the SWHs had gone unnoted, because the electric back-up had provided hot water. Of course, in those cases, energy savings with the solar systems were minimal.

Information on efficiencies and life-times of most of the systems encountered is not known. For the cost comparisons estimations have been made based on design and material parameters (see chapter 3 and appendix I).

5.5. Supply

In the 1980s several companies started activities in the field of solar water heating. Imported systems had to be obtained through Agricultural and Industrial Supplies Company Ltd. (AISCO), a Dar es Salaam based parastatal. It imported systems from the USA and Israel: separated, direct, thermosyphon systems, mainly with electric back-up. They also installed systems at several hotels, but apparently not doing a very good job at it: many systems are reported not to function any more and even never to have performed at all. They don't seem to have done any maintenance either. By now AISCO has stopped its activities in the field of solar water heating.

Jandu Plumbers, an Arusha based company manufacturing a.o. electric and woodfuel boilers, started manufacturing some SWHs some 7 years ago. The costs of manufacturing and installing a few systems per year became too high however and they stopped this effort after a few years. Jandu has expressed its interest in import or local assembly of SWHs, however.

Tropical Solar Systems (TROSS) is a one-man Arusha based company, mainly importing, selling and installing photovoltaic and SWH equipment. It has been in the business of solar water heating since 1983, selling about 16 systems, mainly to households in the Moshi region, where the owner of TROSS lives. The systems installed in the 1980s were imported through AISCO from the USA and Israel: all small, separated, direct, thermosyphon systems with electric back-up. The last few systems were directly imported from Kenya (Solatec), including one large, direct, pumped system with electric back-up. TROSS has expressed interest to start local manufacturing of SWHs and is in contact with a British engineer to jointly start this effort.

Intertec is a Danish-Tanzanian owned company that mainly does electrical and mechanical contracting. They have about 40 employees. Since 1989 solar water heating also forms a small part of their business. During the years they have imported and sold around 19 Solahart systems from Australia: separated, indirect, thermosyphon with electric back-up, mainly to rural-based missions. The systems are installed by the customers. Intertec's systems are relatively expensive compared to the same type of systems that Wilken sells and installs.

Wilken Telecommunications Limited is a small subsidiary (7 employees) of a British-owned company that specializes in telecommunications equipment. They also do photovoltaic equipment to power telecommunications systems. Since about 2 years they started importing, selling and installing Australian systems (Solahart) after the successful example of its Nairobi-based office that started importing the same systems in Kenya 7 years ago. The technical support still comes from Nairobi, but this is supposed to change once sales grow. The Solahart systems are separated, indirect, thermosyphon systems with electric back-up in sizes of 180 and 300 litre (with 2 and 4 m^2 panels respectively). Larger, commercial systems are also possible, but system sizing will then be done through the Solahart regional office in The Netherlands. Up to now Wilken has sold about 17 180 litre systems to one donor agency. In the future they expect to be selling mainly to large hotels and hospitals in urban areas.

Solar Solutions is a small Greek-owned that came to Tanzania 1 year ago. It is specializing in renewable energy equipment, mainly solar photovoltaic and solar water heating systems. It has become an agent for a Greek SWH manufacturing company Helioakme (brand-name: Megasun). The first shipment of SWHs is expected at the end of 1995. Solar Solutions will mainly sell two types of SWHs: a 160-litre, separated, indirect, thermosyphon system with electric back-up (2.5 m^2); and a 160-litre, integrated system with electric back-up (2 m^2).

Pembe Ranch Company Ltd is a small (11 people), Greek-owned general importing company that has been in Tanzania since 1981. Only recently it started to get involved in solar water heating as an agent for the Greek company Sole S.A. (brand name ALPHA). The first shipment of SWHs is expected end of 1995. The systems are direct, integrated systems with electric back-up in three sizes (125, 175 and 200 litre, with 1.5,2 and 2.2 m^2 collector area). Larger, commercial systems would be possible, but sizing and design would have to be done from Greece. The company expects to sell mainly to institutions like hotels, lodges, boarding schools and hospitals.

Nabikia Afrika Ltd. is a small Southafrican-owned importing company, importing various products from South Africa, including SWHs as small part of its business. It started business in Tanzania about one year ago. It has sold 4 SWHs from SOLCO (South Africa). They are 100 litre, 1.79 m^2 direct, integrated systems with no back-up. The systems are made of poly-propylene and are considerably cheaper than the other SWHs. Nabikia expects to mainly sell the systems to private households and lodges in game parks, where there is little other alternative to heat water.

At present no local production of SWHs is taking place in Tanzania. Materials for local production are available. Galvanised steel sheets, pipes, storage tanks and fittings are readily available in various sizes and at reasonable cost (in appendix VI cost estimations of locally produced SWHs are given using different materials at local prices). The steel is imported and galvanised in Dar es Salaam. Sometimes complaints have been uttered on the quality of the galvanization layer. Copper pipes are less easily available and copper sheets or fittings are normally not available. Aluminium sheets are available from Aluminium Africa, aluminium pipes and fittings are not. Hence, systems made from galvanised steel would be a good choice for starting small-scale local production. Ordinary black paint, glass, rubber, soldering equipment, etc. are also available at many stores. Soldering and pipe-bending and fitting is regularly done at many small-scale workshops. Therefore the production skills are also available. Problems are more in areas of design, installation and maintenance. Many designs have been developed by different organisations (a.o. Streib, BACIBO), but these are not readily available. BACIBO has done some projects on training Tanzanians in manufacturing their serpentine SWH, with considerable success.

Alternatively, the supply infrastructure for electric water heaters seems to be more developed. At least two local manufacturers exist in Tanzania (one in Arusha, one in Dar es Salaam), importing metal sheets, electric elements and thermostats. Imported electric heaters are available at many shops in Dar es Salaam, Arusha and Mbeya. Getting somebody to install these heaters should not prove a problem either. The case of woodfuel boilers is less clear: at least one local producer exists and has been in business for more than 10 years (Jandu plumbers), but they were not capable or willing to give more information on the number of woodfuel boilers sold, nor on possible other suppliers.

Chapter 6 Promoting the diffusion of solar water heaters in Tanzania

In this chapter the research findings in Tanzania will be summarized (paragraph 6.1.). Again the framework developed from literature will be used to categorize the opportunities and constraints. With these opportunities and constraints in mind, recommendations can be made as in how to stimulate further diffusion and the possibilities for TIRDO (paragraph 6.2.).

6.1. Summary: opportunities and constraints

Tanzania is endowed with a **favourable physical environment**: especially in the highland areas, where the temperatures are colder and more solar energy is received. Tanzania is endowed with a high solar radiation of an average 4.4 to 6.8 kWh/m^2.day. This is around twice the solar radiation that most of Europe receives and similar to that in Kenya. A possible physical constraint might be the low quality of some of the water supply in Tanzania (e.g. Arusha/Moshi). It favours the use of indirect systems that are more expensive and less easy to produce locally.

Tanzania is a **poor country**, poorer than Kenya and with a less developed middle class that could afford SWHs. Also the tourist industry that stimulated demand for solar water heaters in Kenya, is less developed. At present the economy seems to be picking up, but the prospects are uncertain.

Promotion and institutional support by government, donor and R&D institutions is still limited. In the 1980s CAMARTEC and the University of Dar es Salaam did some research on SWHs, but coordination was lacking and diffusion did not succeed. Some donor organisations invested in solar water heaters for individual developing projects (mainly hospitals and missions), but not systematically in the diffusion process. A Dutch foundation - BACIBO - developed a SWH for local production and succeeded in training local technicians to build and install qualitatively good systems. They still continue their development and training activities. However, local production has remained sporadic: continuous local production has not succeeded yet. At present the University of Dar es Salaam is doing some research on solar water heaters, but mainly for educational purposes. They also offer courses in thermal solar systems. However, Tanzania still lacks trained installation and maintenance personnel for solar water heating.

Import tariffs and sales tax on solar water heaters are **high** (56% cumulative), considerably increasing the price of these systems. In some cases the Tanzanian taxing system puts a double taxation on locally produced SWHs: both on the raw materials (import and sales tax) and additional sales tax on the sale of systems. This particularly affects small-scale producers.

Energy prices were very low, especially electricity prices for households were heavily subsidized. Since the beginning of the 1990s electricity prices have been **rising**. Furthermore Tanzania has been suffering from a shortage in electric generating capacity. This has made electricity supply unreliable.

An estimated 100 **systems** have been installed[23], representing 500 - 1000 m^2 of collector area. Most of the systems are of the **separated, direct thermosyphon type** with electric back-up. Thermosyphon systems seem the most appropriate in Tanzanian circumstances, because of their simplicity and independence of an unreliable electricity supply. However, many of the installed systems are suffering from installation and maintenance problems. The mostly used alternative technology is electric water heating.

The **main reasons for using solar water heaters** are the cost reduction on the long run and the problems with supply of conventional energy sources - be it electricity, IDO or woodfuel. The main constraints mentioned are: high investment costs and unawareness of the solar option or its availability. The investment costs in SWHs are very high as compared to conventional alternatives, even if in the long run they might be more economic in some cases. The high import tariffs and sales tax - a cumulative taxation of 56% - make solar systems even more expensive than conventional alternatives, because investment costs form a large part of the costs for solar heated water. The knowledge and expertise on SWHs seems to be low. In general awareness of energy costs and the need to save energy seem to be low in Tanzania, but this is slowly changing, particularly concerning electricity after the high increases in electricity prices in the last years.

Most of the solar water heaters found in Tanzania at the moment are used in the **urban commercial/institutional sector**. Indications are that the main market for SWHs in the near future are the urban institutional sector and possibly urban middle and high income households. Factors favouring the use of solar water heaters in the commercial sector are: the much higher electricity prices paid, the easier access to investment capital and the lower prices per m^2 of collector area for larger systems. The cost comparisons with electric water heating in appendix I show a pay-back period of 2.5 to 3.1 years for such institutions and annuity costs that are 1.5 times lower than with electric water heating. With a growing tourist industry especially the market with hotels looks promising, representing a potential market for 8,000 m^2 of collector area. For urban as well as rural households solar water heaters more expensive than conventional water heating (electric and woodfuel respectively).

The **two most promising markets** are the urban institutional and household sectors. These are a richer, 'up-class' market with easier access to foreign capital and a probable taste for imported, high-quality products. This seems to be corroborated by evidence from Kenya and other countries (Bruggink, 1984). Studying the results of the sensitivity analysis in appendix I, shows that investment costs have the largest influence on annuities for solar water heaters, while fuel costs determine the costs for conventional electric water heating. Removing sales tax from water heating equipment and bringing electricity tariffs to real cost levels, would make solar water heaters less costly than electric water heating, even for urban households. Other factors, like changes in life-time, solar contribution (e.g. increased efficiency), or capital costs (discount rate) seem less important. Of course, in practise, the mere availability of and access to capital will remain an important factor - irrespective of its costs. Institutions will probably remain at an advantage in access to investment capital.

---

23 73 systems are listed in appendix II, but an additional 20 to 30 more are supposed to have been installed without it being known by the author.

A concentration of systems installed seems to take place in the Arusha area, which is closer to the Kenyan **supply infrastructure**. The diffusion system is clearly decentralised, consisting of a few small and mostly recent private companies. Apparently in the 1980s import of SWHs was controlled through the parastatal AISCO because imports had to be done through them A few other companies were involved in solar water heating. Markets were small, however, reduced even further by import restrictions and low electricity price. One company attempted local production before, but gave it up after it proved to be too expensive to produce for such a small market. At present no commercial scale manufacturing of SWHs is taking place in Tanzania; only one of the 1980s companies survived through the 1990s and continued importing SWHs. But in the last few years several new companies have started venturing in this field, introducing imported indirect and integrated systems in Tanzania. All these companies are small and have little experience in installation and maintenance. Of the **6 companies active in solar water heating** at present, 4 are foreign-owned. None of the companies concentrates merely on SWHs, in fact these represent only a small part of their activities. Strategies on market segmentation, pricing, promotion or infrastructure have hardly been developed, yet. All companies seem to compete in the same, small market. Furthermore the build-up of expertise in the field of installation and maintenance seems very limited. Of course most companies have only recently started venturing in the field of solar water heating, but the number of systems badly installed in the past, proves the danger of a lack of expertise. Also information on potential clients and competition is scarce.

Local production on a small-scale and at competitive prices seems to be possible in Tanzania: designs have been developed that function well under local conditions and production possibilities (BACIBO-design, Deuss, 1987, see also appendix VI). The present small size of the market would make production relatively more expensive. It doesn't justify much investment in equipment, R&D and marketing, while at the same time the risks are high. High prices and duties of imported raw materials also increase the price of local production. Also at present design information is not easily available to interested parties.

The main facts on the diffusion of SWHs in Tanzania have been listed in table 6.1.

period (years)	institutional environment	technologies used	infrastructure	users
1980s	- low energy (electricity) prices - taxation + CAMARTEC + BACIBO + UDSM-physics	separated, direct, thermosyphon, with electric back-up - damaged systems	decentralised diffusion system - few agency's involved	+ urban institutional sector (hotels, hospitals, missions) + reason: cost reduction ? environmental reasons + non-availability conventional fuels - high investment
1990s	+ rising electricity prices + electricity shortage - taxation + TIRDO + UDSM-engineering + BACIBO	introduction of indirect and integrated systems with electric back-up ? unknown performance	+ new agencies - promotional activities - expertise + concentration in Arusha area	+ urban institutional sector ? affluent urban households + reason: cost reduction ? environmental reasons + non-availability conventional fuels. - high investment - knowledge, expertise

Table 6.1. summary on diffusion of solar water heaters in Tanzania

6.2. Stimulating the diffusion process and possibilities for TIRDO

It is clear that solar water heating is in an initial stage in Tanzania. Only a very small number of systems have been installed and infrastructure development has remained very limited. As such, one could say that no diffusion system has developed yet. Despite the many constraints, possibilities are there to stimulate the development of such a system and - consequently - the diffusion of solar water heater technology itself.

The case of Kenya shows that development of a solar water heating market and infrastructure through private initiative is very well possible, but also the weaknesses have been described: little local R&D and connection between R&D and solar water heating companies, no quality control, personnel problems, no concerted effort for promotion. It is very likely that the diffusion of solar water heaters in Tanzania will develop along similar lines as in Kenya. Already quite a few solar water heaters installed in Tanzania originate or came through Kenya. This will only increase with the strengthening of regional cooperation (e.g. the attempts to revive the former East African Community between Tanzania, Kenya and Uganda and the development of the Preferential Trade Area for East and Southern Africa) and the liberalization of Tanzanian and Kenyan economies. Several firms in Nairobi have expressed their interest in the Tanzanian market for solar water heaters. Some measures could be taken, however to stimulate and improve the diffusion process.

Considering the examples of Kenya and the situation in Tanzania, the most effective approach is one of institutions creating an **'enabling environment'** with a mix of instruments, leaving the actual diffusion activities to private companies. A concentrated effort, including government, TIRDO, solar companies; possibly TANESCO and donor organisations would be most effective. Institutional measures can be grouped along two lines: **a) stimulating demand; b) supporting the supply infrastructure.**

Stimulating demand

Stimulation of demand could take four shapes:

Cost reduction: one measure would be to remove or lower duties and sales tax on solar water heaters as is the case for photovoltaic solar modules. This would lower investment costs, the largest constraint recognized, considerably. Especially the removal of sales tax would have the advantage of lowering the price of both imported and local solar water heaters, while maintaining a comparative advantage for local products. Furthermore, removing tax is less elaborate policy instrument than implementing a subsidy. Additionally the setting of electricity tariffs at real cost levels would improve the comparative cost advantage of solar water heaters. It is not likely that such a measure would be taken merely for the introduction of solar water heaters, but the reform of electricity prices has already been started by TANESCO and the Tanzanian government to stimulate the rationalisation of energy use in Tanzania. By the turn of the century electricity tariffs should reflect real costs.

Guarantee of a minimum market: government or parastatals could invest in solar water heaters for housing and other building projects. This was done for instance by the Kenyan government in the 1980s. Using this instrument would at the same time give government some control over the solar water heating infrastructure, which could for instance be used to introduce some quality control or stimulate local production.

Providing information and promotion: the promotion of solar water heating (and solar energy in general) seems necessary to make people aware of the possibilities. Such promotion could be done using various instruments: media campaigns, demonstration projects, etc. A cooperative effort between government and solar companies would be most effective. Some of these companies have already taken the initiative to start a Tanzania Solar Energy Society. If well used, information could also be an instrument for government to introduce some quality control, e.g. by providing information on reliable suppliers.

Credit: another promising area of intervention would be the provision of credit for the purchase of solar water heating equipment. Some countries already have experience with setting-up revolving funds, especially for solar photovoltaic equipment, but the same set-up could be used for solar thermal equipment. Another attractive option would be a from of hire/purchase in cooperation with the electricity company TANESCO. For TANESCO it could mean an additional instrument of Demand Side Management for electricity savings[24]. Research would be needed in this area.

Supporting supply infrastructure

This support could take several forms:

Provision of information: on solar radiation wind and water quality data; on experiences with different systems and possible designs for local production.

Expertise-building: training in local production techniques, installation, maintenance and repair; possibly in marketing and after-sales.

Test-facilities: facilities for testing efficiency, life-times and other performance characteristics of different types of systems under different (local) circumstances. These facilities could be an instrument in quality control.

Supporting services: services to supply companies, such as provision, calibration and repair of instrumentation; help with technical problems, e.g. design and installation of large complex systems and monitoring.

24 Because the solar contribution in the day-time partly coincides with electricity demand peaks, the use of solar equipment could also be an instrument in reducing peak demand and therefore generating capacity.

Possibilities for TIRDO

As mentioned at the beginning of this paragraph, the most effective would be a package or mix of measures mentioned: stimulation of demand with concurrent support of supply infrastructure. Many of the demand measures would be in the hands of government agencies e.g. Ministry of Finance, Ministry of Water, Energy and Minerals). TIRDO's role would best be in the support of supply infrastructure.

Traditionally the role of R&D institutions in developing countries, like TIRDO, was to concentrate on the generation and adaptation of technologies. Since it has been shown that such technologies have already been developed and adapted to local circumstances by an organisation as BACIBO (Deuss, 1987; Streib, 1989), it would be more advisable for TIRDO to concentrate on acquiring this technology, including it into a wider program of technology transfer to interested producers and supportive services.

One could envision TIRDO as a future 'centre of excellence' in the field of solar, providing information and services to companies, doing test and improvements on solar systems, providing training, testing and monitoring facilities, advising government and other institutions on possibilities. One option, for instance, to promote the development of a sustainable solar supply infrastructure would be to institute some quality control. Officially quality control and standardisation are the responsibility of the Tanzania Bureau of Standards: they have the legal authority to set technical standards. This would require an organisation with technical expertise to monitor installed solar systems and with a central position in the diffusion network. Often another organisation is contracted to do the actual work. TIRDO could take up such a role and make it into a cooperative effort.

At present TIRDO does do not have the specific technical expertise in this field, yet, and it does not seem to be available in Tanzania at present. What TIRDO does have, is a technical staff, competent in various fields of engineering, energy management, material testing and industrial support services. At present TIRDO is the focus of efforts to set-up a National Cleaner Production Centre and a Centre of Excellence for R&D in the fields of industry and environment. Therefore they do have sufficient general expertise and background available and they have shown interest in developing specific expertise in the field of solar technologies. Contacts have been made with relevant European institutions, but it should be clear that the development of such expertise and supportive infrastructure is a long process requiring considerable effort and finance. Starting simple and slowly building up expertise in cooperation with solar companies and government institutions, could lead to the creation of a sustainable solar infrastructure and market.

APPENDICES

Appendix I: micro-economic cost comparison of water heating technologies

The application of solar water heaters involves the substitution of higher initial investment costs for lower operating and fuel costs in subsequent years. Two instruments are used to evaluate whether this substitution is micro-economically viable: the simple pay-back period and annuities or annualized costs, for which some assumptions have to be made.

simple pay-back period

The simple pay-back period is calculated as the period (in years) that is needed to earn back the *additional investment* in a solar water heater by its energy savings:

$$pbp = d_{inv}/d_{fuel}$$

pbp is the simple pay-back period
d_{inv} is the difference in investment
d_{fuel} is the fuel savings using the solar water heater: the prices of fuels are assumed to grow with inflation, i.e. remain constant in real terms during the calculated period;

Problem with the simple pay-back period is that no provision for the costs of capital, maintenance and repair are made. This is particularly if pay-back periods turn out to be long (longer than 2 years) and/or capital costs are high, as is the case in many developing countries.

annuities

Annuities are calculated as the virtual yearly cost of the energy service, made up of investment (capital) costs, operational costs and fuel costs:

$$a_{tot} = a_{oper} + a_{fuel} + a_{inv}$$

- a_{tot} is the total annualized costs or annuities.

- a_{oper} is the annual operation, maintenance and repair costs.

It is assumed that these can be given as a percentage of the initial investment costs: in these cases for solar water heaters 1.5 % annual O&M costs will be accounted for against 5% for conventional systems reflecting the relatively lower O&M costs for solar systems. Since the investment cost in solar water heaters is much higher, the annual real costs accounted for will be in the same order of magnitude.

- a_{fuel} is the annual fuel costs.

As a first approximation fuel price and operational costs inflation equal the general rate of inflation, i.e. real prices for conventional fuels and operational costs remain constant. In the past overly optimistic predictions about the future of various renewable energy technologies have been made under the assumption of steeply rising fuel prices. Therefore the assumption of constant real fuel and operational costs seems reasonable.

- a_{inv} is the annualized investment costs:

$$a_{inv} = I\,[r(1+r)^T] \,/\, [(1+r)^T-1]$$

I is the initial investment and $[r(1+r)^T] / [(1+r)^T-1]$ is the annuity factor
T is the economic life-time of the systems; economic life-time is considered to be equal to technical life-time;
r is the discount rate: a discount rate is used to reflect the costs of capital;

In real terms annual operational and fuel costs are considered to be constant. Using an annuity factor transforms initial investment costs into a stream of constant (in real terms) running costs, while different economic life-times are reflected by according annuity factors. The main problems with this method involve the choice of economic life-time and discount rate. Particularly the issue of discount rates has inspired many economic debates. Discount rates are supposed to reflect the amount of additional consumption required in the future (at time t+1) to compensate for the loss of consumption at the time of investment (t) and the risk taken on investment. This compensation might be different for different groups and sectors in society, but for practical purposes of project evaluation a generalized discount rate is necessary[1]. Under ideal circumstances (in a world with perfect knowledge) one would use a real interest rate: market interest rate (i in %), corrected for anticipated price changes (inflation: a in %):

$$i^{+} = (i-a)/(1+a)$$

However, in real circumstances and especially in many developing countries interest rates are often lower than inflation rates, which would mean calculations with negative discount rates. This is due to the fact that interest rates are generally fixed in the form of maximum legal interest rates set by government. These standards often do not reflect the real capital scarcity in developing countries, but political priorities, such as efforts to keep public sector debt low. In Tanzania, for instance, interest rates for medium to long term loans were between 31 and 38% in 1995 (Bank of Tanzania, 1995), while rates fluctuated between 27 and 45% for short term loans. With an average annual inflation real interest rates therefore varied from -0.55% to 13.5%. One discount rate will have to be 'chosen'. In the cost calculations an initial discount rate of 12% is used in accordance with the MWEM and SADC[2]. Oelert quotes a discount rate of 7% as not being too unreasonable. This rate is used in a sensitivity analysis.

- It is also assumed that the liquidation yield of systems at the end of their economic life-time, can be ignored.

Calculation of fuel costs

1. establish the amount of hot water needed per day (in litres);
2. establish the cold water inlet temperature and the temperature of the hot water needed (in this case 20 and 60 °C respectively) to find the temperature raise that is needed (40°C);
3. multiply the amount of water needed with the temperature raise and with the specific heat of water (i.e. the energy needed to heat 1 litre of water with 1 °C: 1.16 Wh/ l.°C);
   $thermal\ demand = l_{hw} \times dT \times 1.16$

This thermal energy demand can be delivered by different technologies: solar, electric, woodfuel. The amount of thermal energy a solar water heater can deliver is calculated by multiplying the collector area installed with the yearly mean average daily solar radiation and the efficiency of the panels. In some cases the thermal energy can not be met completely with solar energy (cases 1,2,4,5). The remaining thermal demand will have to be delivered by the conventional auxiliary heating system. The remaining thermal energy demand is divided by the efficiency of the conventional system to calculate the amount of energy - i.e. fuel - needed. This is multiplied with the fuel price to result in the annual fuel costs.

---

1 In reality for instance the cost of capital for households will generally be much higher, since it is more difficult for them to get access to capital.

2 MWEM: personal communication with mr. Kitange, economist at MWEM; SADC; Assessment of the market for photovoltaic equipment in the SADC-region; 1994.

In this appendix the micro-economic comparison will be performed on 5 cases:

1. urban household in Tanzania
2. urban institution (hotel) in Tanzania
3. rural household in Tanzania
4. industry in Tanzania (only pay-back period)
5. urban household in Kenya

General data Tanzania (cases 1 to 4)

Exchange rate: 1 US$ = 630 Tshs		
Discount rate: 12 %		
Solar radiation: 4.6 kWh/m².day		
Fuel prices	**burning value**	**price per MJ**
electricity (households) : 45 Tshs/kWh		12.5 Tshs/MJ
electricity (institutional) :100 Tshs/kWh		27.8 Tshs/MJ
furnace oil (F.O.) :127 Tshs/litre	39.4 MJ/litre	3.2 Tshs/MJ
fuel wood : 40 Tshs/kg	15.5 MJ/kg	2.6 Tshs/MJ

All investment prices include installation costs, estimated at 10% of the equipment costs. For conventional technologies (electric and wood) these are based on quotations by the only local producer traced (Jandu plumbers, Arusha). Prices of imported solar water heaters are based on Solahart equipment, quoted by one of the more prominent - new - importers (Wilken, Dar es Salaam). Prices of local solar water heaters are baed upon estimations (see appendix VI) using the BACIBO-design (Deuss, 1987). Efficiencies and life-times of equipment are estimated using Streib (1989) and Andersson (1984). Fuel prices were quoted by TANESCO and MWEM. Estimations of electricity prices based on real costs come from a 1993 tariff study (TANESCO, 1993). For the industrial case only a pay-back period is calculated since such a system would function as a pre-heat system (still needing conventional fuel boilers) and no quotations on such boilers could be found.

To estimate the influence of changing input parameters on annual costs, a **sensitivity analysis** is done on the cases 1 and 2 - the most promising markets in Tanzania.
In case I.b. sales tax is removed from <u>all</u> water heating equipment, lowering investment prices by 30% and thereby investment and O&M costs.
In case I.c. a real cost electricity price of 70 Tshs is used, increasing fuel costs by more than 50%.
In case I.d. the removal of sales tax in combination with the use of real electricity prices is evaluated.
In case I.e. investment costs are lowered by using a lower discount rate (7%).
In case I.f. investment costs are lowered by extending life-times with 5 years.
In case I.g. the solar contribution is increased with 17% by using a higher solar radiation figure (5.38 kWh/m².day, the yearly average radiation for Arusha).
In case II.b. the influence of lowering the electricity price for institutions to real cost rate (70 Tshs, a 30% drop) is evaluated.

General data Kenya

Exchange rate: 1 US$ = 58.6 kshs	Solar radiation: 5.5 kWh/m².day
Discount rate: 12%	Electricity price: 4.3 kshs/kWh

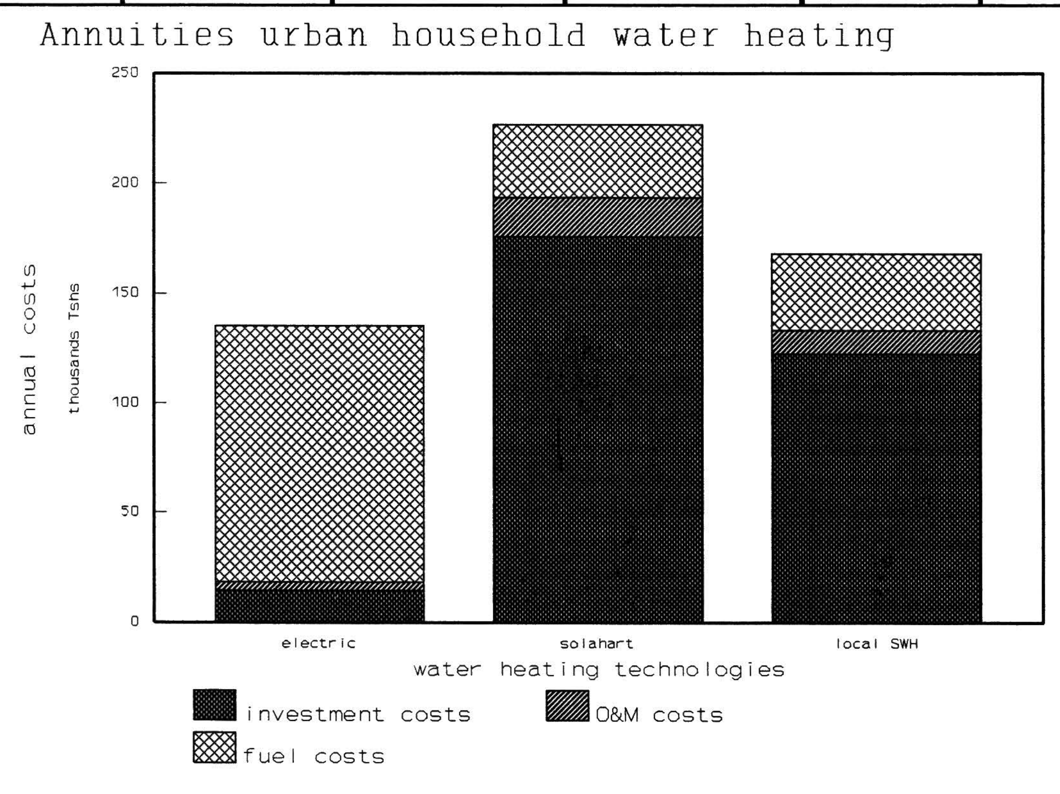
Investment prices are equipment prices quoted by sales companies, plus 10% installation costs. The conventional electric boilers are produced by a local company (Aquaken). The Solahart water heater is representative for imported solar water heaters; Solatec for locally assembled solar water heaters and Italproducts is the only reliable locally produced solar water heater. Efficiencies and life-times are estimated using Streib (1989) and Andersson (1984). Electricity prices were quoted by the national electricity company (KP&LC).

I.a. urban household Tanzania

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		10
imported solar water heater (Solahart, 180 l)	1197000	90	55 2 m^2	15
local solar water heater (copper, 180 litre)	694000	80	45 2.5 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		14443	4058	116910	135411
imported solar water heater (Solahart, 180 l)	11.1	175749	17955	32985	226689
local solar water heater (copper, 180 litre)	7.5	122827	10410	34903	168140

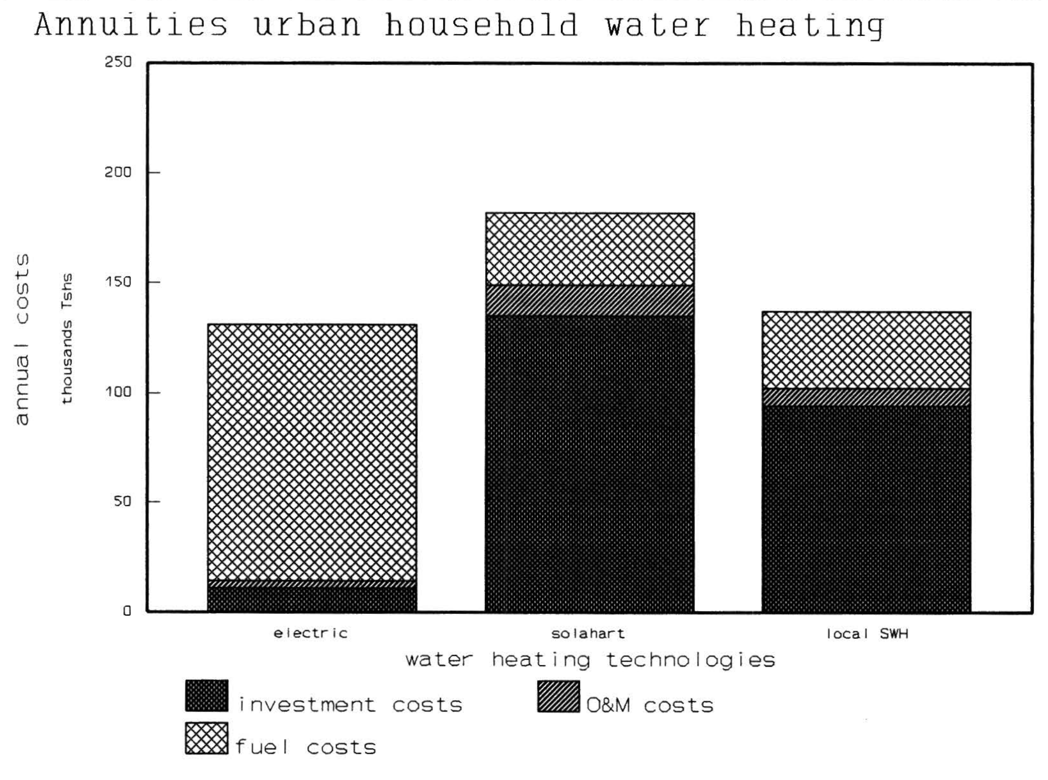


I.b. urban household Tanzania: no sales tax on all water heating equipment

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m²)	life-time (years)
local electric water heater (Jandu, 90 litre)	62700	80		10
imported solar water heater (Solahart, 180 l)	920769	90	55 2 m²	15
local solar water heater (copper, 180 litre)	533845	80	45 2.5 m²	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		11096	3122	116910	131128
imported solar water heater (Solahart, 180 l)		135192	13812	32985	181988
local solar water heater (copper, 180 litre)		94482	8008	34903	137393

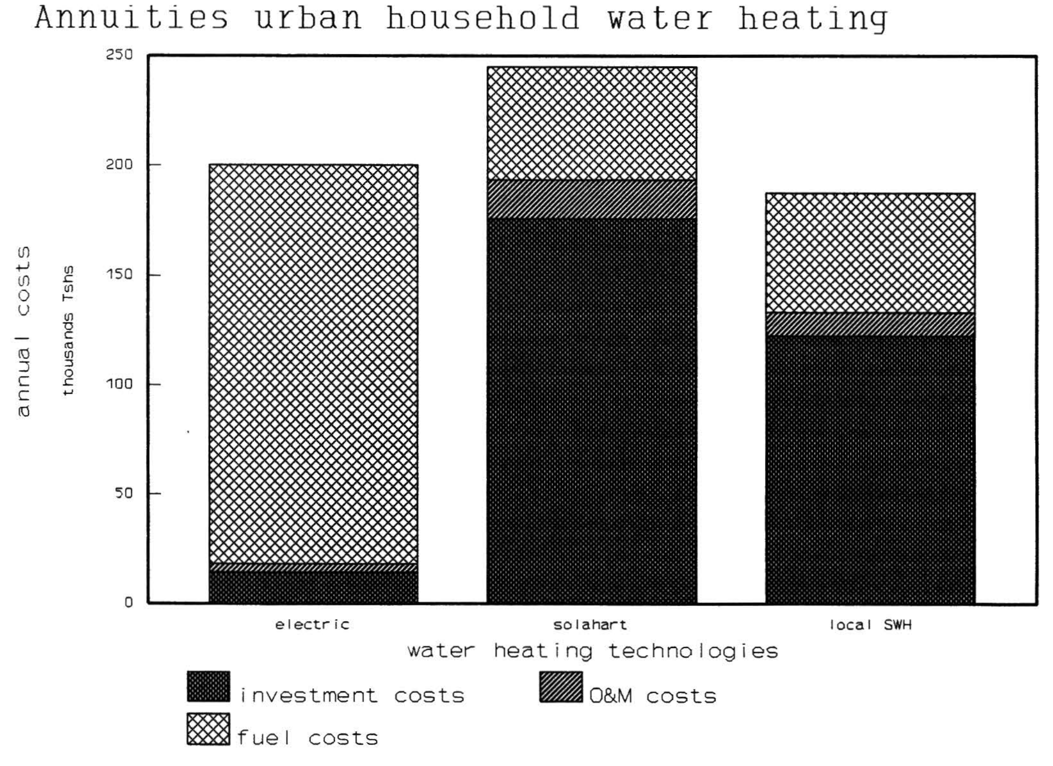


I.c. urban household Tanzania: real electricity prices

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		10
imported solar water heater (Solahart, 180 l)	1197000	90	55 2 m^2	15
local solar water heater (copper, 180 litre)	694000	80	45 2.5 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		14443	4058	181860	200361
imported solar water heater (Solahart, 180 l)		175749	17955	51310	245014
local solar water heater (copper, 180 litre)		122827	10410	54294	187531

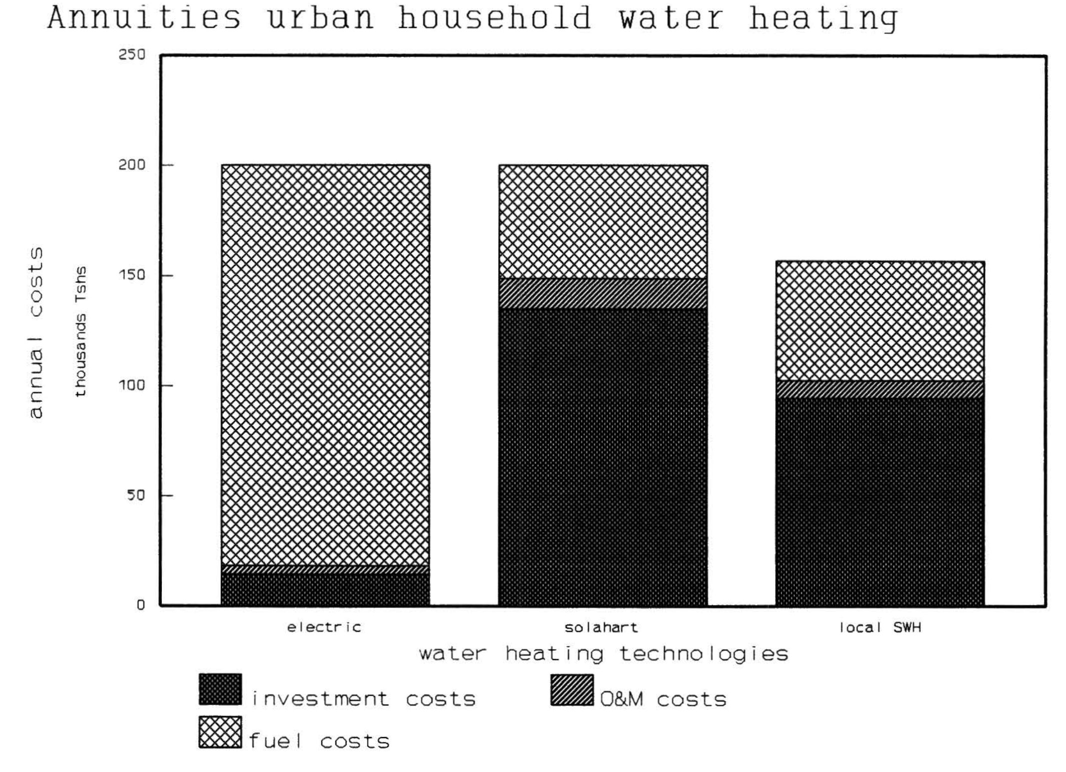


I.d. urban household Tanzania: no sales tax on SWH equipment <u>and</u> real electricity price

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		10
imported solar water heater (Solahart, 180 l)	920769	90	55 2 m^2	15
local solar water heater (copper, 180 litre)	533845	80	45 2.5 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		14443	4058	181860	200361
imported solar water heater (Solahart, 180 l)		135192	13812	51310	200314
local solar water heater (copper, 180 litre)		94482	8008	54294	156784

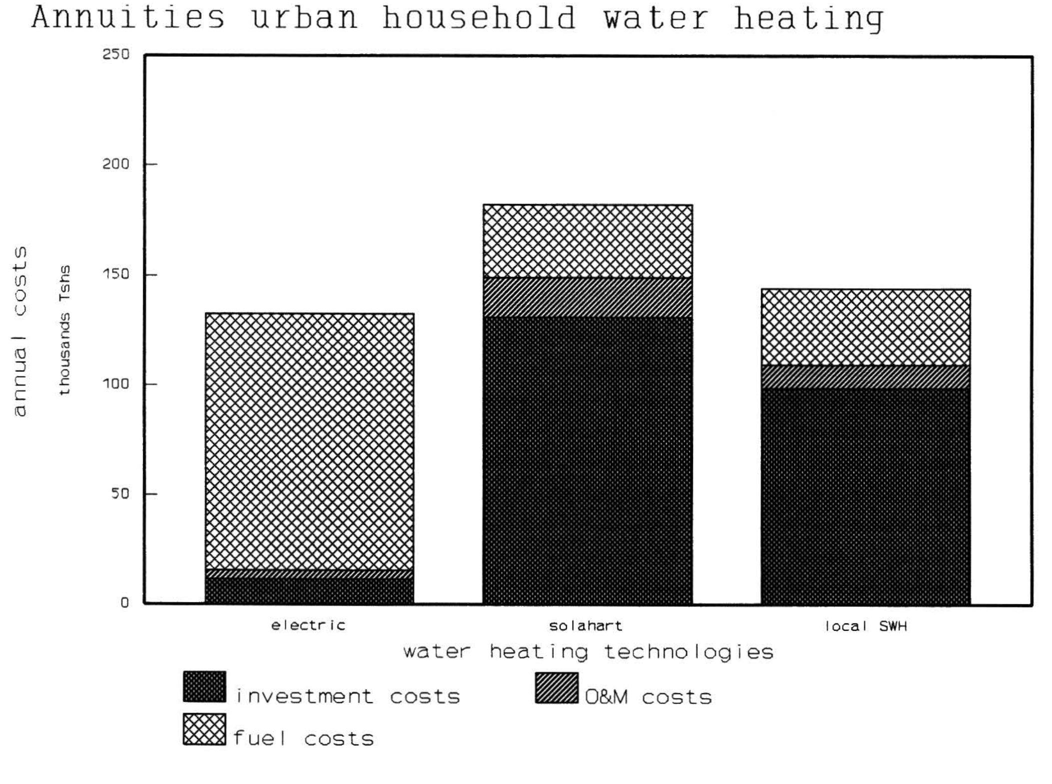


I.e. urban household Tanzania: decreased discount rate

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		10
imported solar water heater (Solahart, 180 l)	1197000	90	55 2 m^2	15
local solar water heater (copper, 180 litre)	694000	80	45 2.5 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		11619	4058	116910	132587
imported solar water heater (Solahart, 180 l)		131424	17955	32985	182364
local solar water heater (copper, 180 litre)		98810	10410	34903	144123

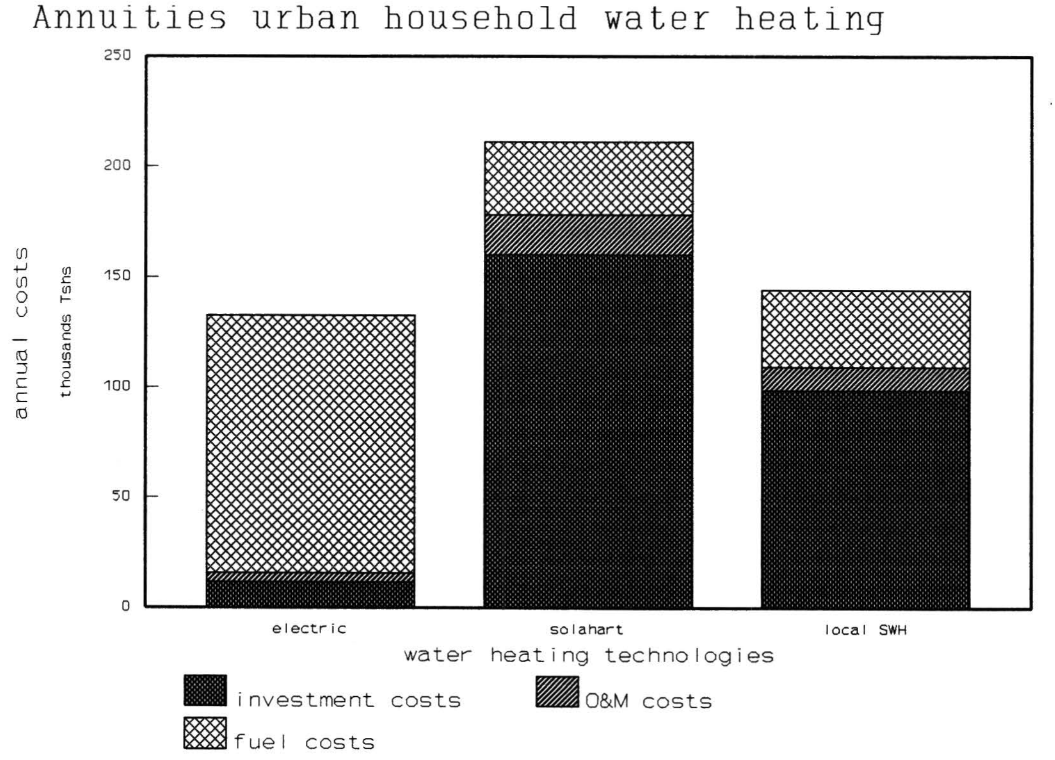


I.f. urban household Tanzania: prolonged life-time

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		15
imported solar water heater (Solahart, 180 l)	1197000	90	55 2 m^2	20
local solar water heater (copper, 180 litre)	694000	80	45 2.5 m^2	15

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		11982	4058	116910	132950
imported solar water heater (Solahart, 180 l)		160253	17955	32985	211193
local solar water heater (copper, 180 litre)		101896	10410	34903	147209

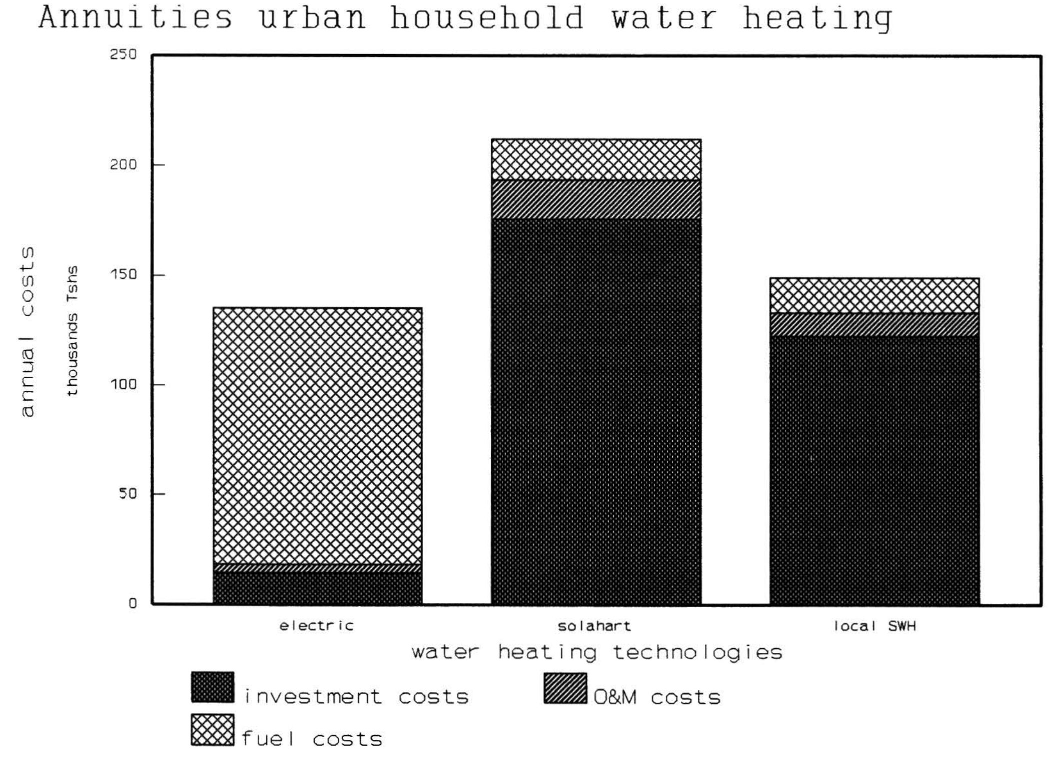


I.g. urban household Tanzania: increased solar contribution

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 90 litre)	81510	80		10
imported solar water heater (Solahart, 180 l)	1197000	90	55 2 m^2	15
local solar water heater (copper, 180 litre)	694000	80	45 2.5 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 90 litre)		14443	4058	116910	135411
imported solar water heater (Solahart, 180 l)		175749	17955	18394	212098
local solar water heater (copper, 180 litre)		122827	10410	16108	149345

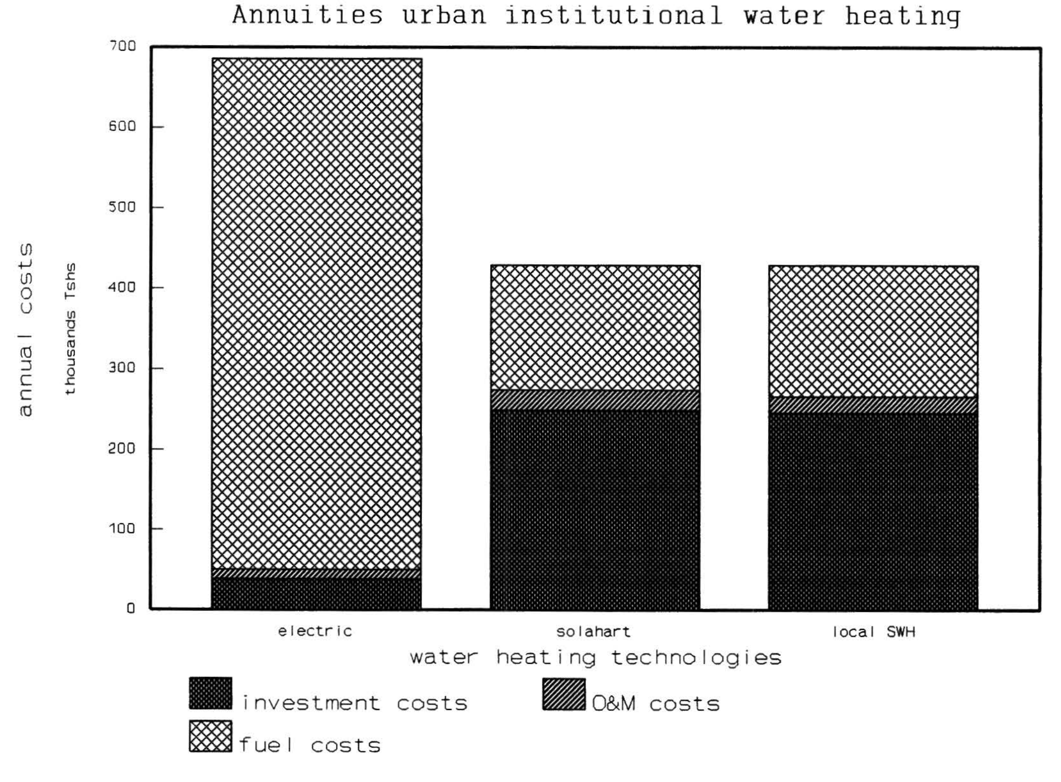


II.a. urban institution (hotel) Tanzania

Assuming 300 litre of hot water per day (small, decentralized system)
Thermal energy demand: 13.9 kWh/day
365 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 225 litre)	221650	80		10
imported solar water heater (Solahart, 300 l)	1701000	90	55 4 m^2	15
local solar water heater (copper, 360 litre)	1388000	80	45 5 m^2	10

technology	pay-back period (years)	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 225 litre)		39229	11083	635100	685411
imported solar water heater (Solahart, 300 l)	3.1	249601	25500	154100	429201
local solar water heater (copper, 360 litre)	2.5	245654	20820	162900	429374

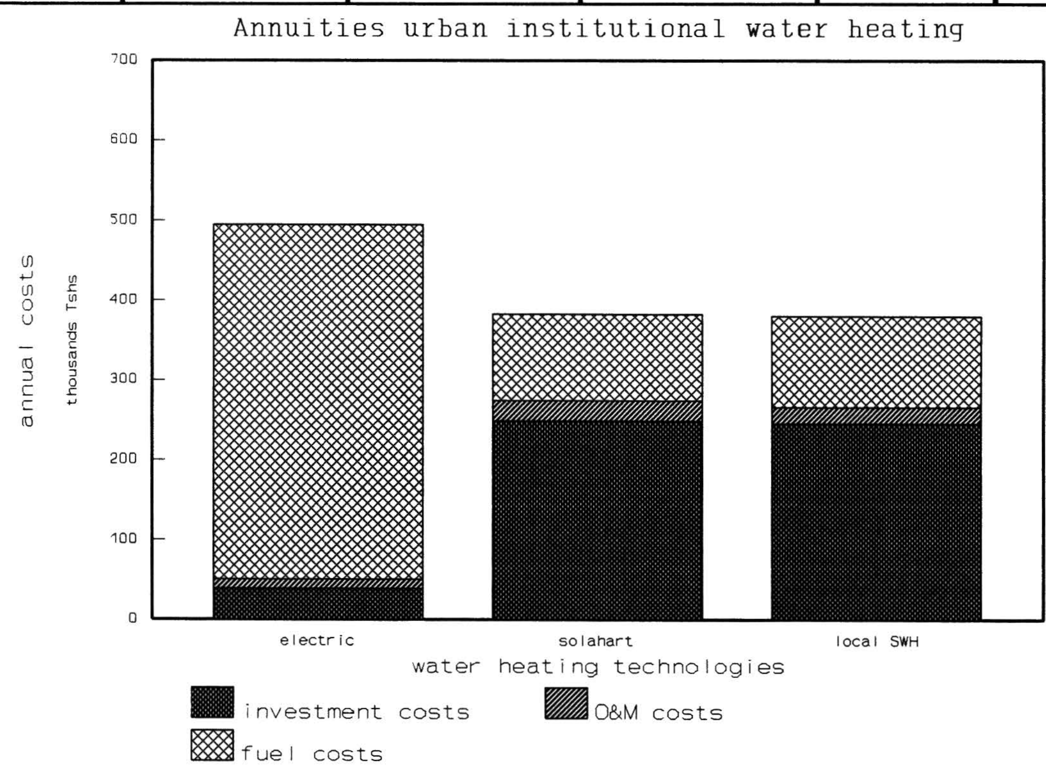


II.b. urban institution (hotel) Tanzania: decreased electricity price

Assuming 300 litre of hot water per day (small, decentralized system)
Thermal energy demand: 13.9 kWh/day
365 days per year

technology	price (Tshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local electric water heater (Jandu, 225 litre)	221650	80		10
imported solar water heater (Solahart, 300 l)	1701000	90	55 4 m^2	15
local solar water heater (copper, 360 litre)	1388000	80	45 5 m^2	10

technology	pay-back period (years)	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local electric water heater (Jandu, 225 litre)		39229	11083	444570	494882
imported solar water heater (Solahart, 300 l)	3.1	249601	25500	107870	382971
local solar water heater (copper, 360 litre)	2.5	245654	20820	114030	380504

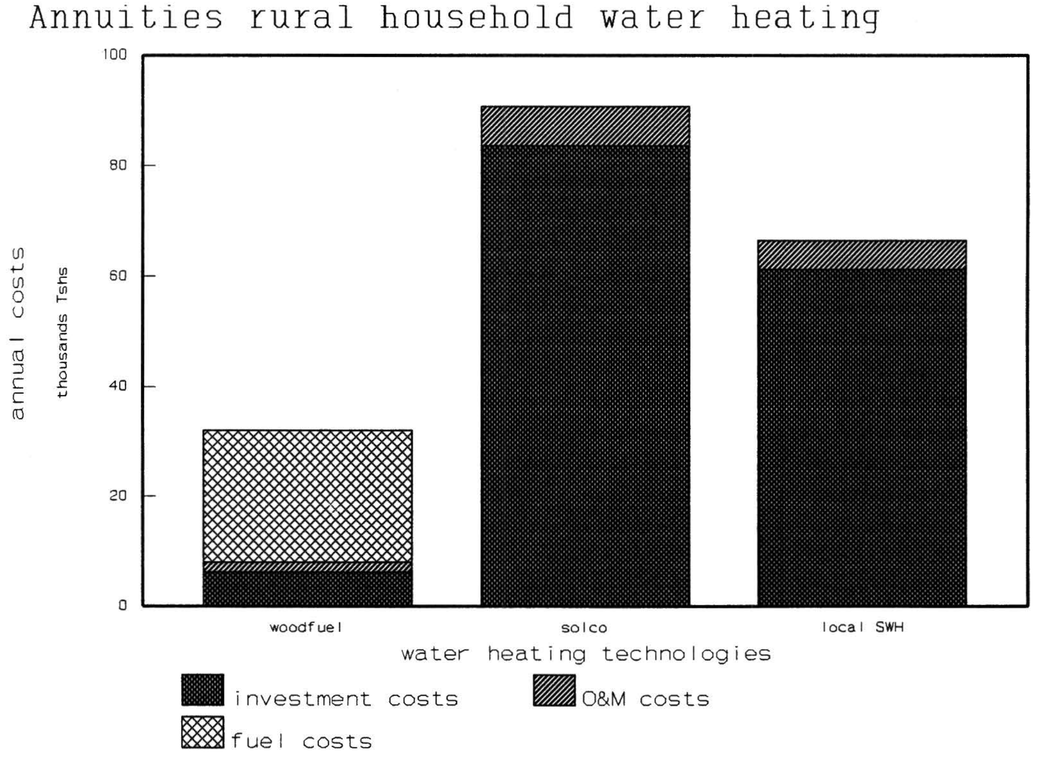


III rural household in Tanzania

Assuming less hot water demand: 65 litre
and simpler solar water heaters (no back-up)
Thermal energy demand: 10.9 MJ/day
Used 340 days per year

technology	price (Tshs) installed	energy efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
local woodfuel water heater (Jandu)	35750	40		10
imported solar water heater (Solco, 100 litre)	472500		40 1,76 m^2	10
local solar water heater (150 litre, galvanized steel)	335000		35 2 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
local woodfuel water heater (Jandu)		6327	1787	23995	32109
imported solar water heater (Solco, 100 litre)	18.2	83625	7088	-----	90712
local solar water heater (150 litre, galvanized steel)	12.5	61325	5198	-----	66522



IV industry Tanzania

For the industrial case a pre-heating system is presumed: a conventional system will still be necessary and only the fuel savings (furnace oil) are calculated against the complete investment.

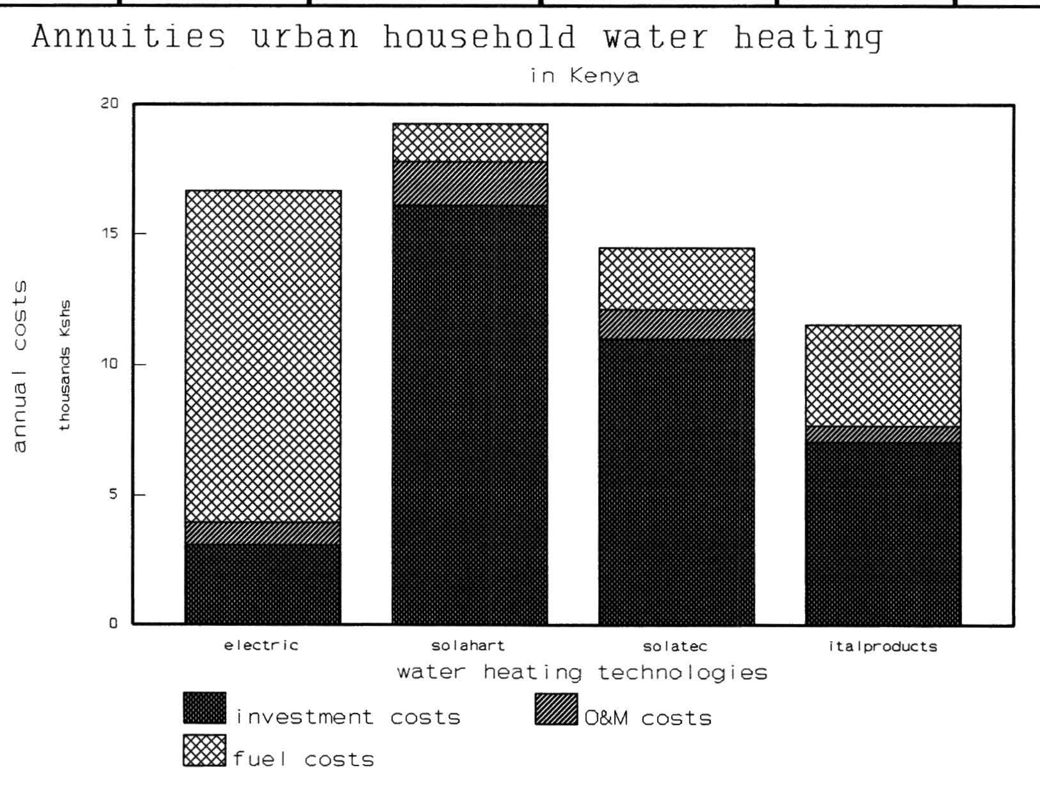
technology	price (Tshs) installed	efficiency (%)	boiler efficiency (on furnace oil)	pay-back period
imported solar pre-heating system	21420 per m^2	50	80 %	17.7 years

V urban household in Kenya

Assuming 150 litres of hot water demand per day
Thermal energy demand: 7 kWh/day
340 days per year

technology	price (Kshs) installed	electric efficiency (%)	solar efficiency (%) + panel area (m^2)	life-time (years)
electric water heater (Aquaken)	17490	80		10
imported SWH (Solahart, 180 l)	110000	90	55 2 m^2	15
locally assembled SWH (Solatec)	75000	90	50 2 m^2	15
locally produced SWH: Italproducts	40000	80	40 2.2 m^2	10

technology	pay-back period	annual investment cost	annual operational cost	annual fuel cost	total annual cost
electric water heater (Aquaken)		3095	875	12717	16687
imported SWH (Solahart, 180 l)	9.1	16151	1650	1478	19279
locally assembled SWH (Solatec)	6.4	11011.82	1125	2372	14509
locally produced: Italproducts	2.8	7079	600	3874	11554



Appendix II: List of solar water heating systems in Tanzania

sources of information:

Sawe E. Sawe; Renewable energy policies in Tanzania; in: M.J. Mwandosya, M.L. Luhanga (eds); Proceedings of the seminar on national energy policy for Tanzania - 10-14 September 1990, Arusha; Stockholm Environment Institute 1991;

COST C.X. Ngosi, A. Towo; A study and assessment of energy projects and their effective utilization in Tanzania; Tanzania Commission for Science and Technology (COSTECH), March 1994;

TIRDO Tanzania Industrial Research and development Organization (TIRDO); pre-study on solar water heating in Tanzania;

TROSS information from Steve Kitutu, director of Tropical Solar Systems, Arusha, a company importing and installing solar water heaters from Kenya;

Jading Y. Jading, e.a.; Solar water heating in Tanzania: minor field study at Nkinga Hospital and Nzega Swedish School; MSc thesis, Chalmers University of Technology, Göteborg, Sweden, 1992;

Own own observations by author;

In all described cases the solar systems are supposed to be direct, thermosyphon systems without back-up, unless otherwise specified.

1. CAMARTEC, Arusha
source: Sawe, COST, own
install: AATP, 1978 (?)
Arusha Appropriate Technology Project (AATP) developed and produced a SWH
1 example at CAMARTEC-compound, Arusha; in bad state however.

2. Hotel 'saba saba' (77), Arusha
P.O.Box 187, Arusha
tel: 057-3800
source: Sawe, COST
instal: 1987, AISCO
120 collectors with back-up heaters, imported from Israel: Electra. still functioning, but not to satisfaction: problems with leaking panels;
electricity savings less than expected; orientation panels to the south
some collectors in bad state (glass broken).

3. New Arusha Hotel, Arusha
bushtrekker chain
source: Sawe, COST, own; install: AISCO, 1987/9
21 imported systems from USA (MLU Engineering) with 1 big isolated tank with 2 el. back-up heaters; apparently systems never functioned; state of decay.

4. Equator hotel, Arusha
bushtrekker chain
source: COST, own
install: AISCO, 1987
28 imported systems from USA (MLU Engineering), apparently never worked

5. Old Arusha Clinic, Arusha
source: TROSS, own
install: 1994 (bought 1984)
2 MLU Engineering, 120 l with electric back-up

6. private person, Machame
source: TROSS, own
install: 1984, TROSS
2 MLU Engineering, 120 l with electric back-up
1 self-made, 1980s, still working, but paint flaked off

7. private person, Machame
source: TROSS
install: TROSS
2 Electra, 120 l with electric back-up

8. private person, Machame
source: TROSS
install: TROSS
2 Electra, 120 l with electric back-up

9.	private person, Machame	source: TROSS install: TROSS 2 Electra, 120 l with electric back-up
10.	private person, Machame	source: TROSS install: TROSS 1 Electra, 120 l with electric back-up
11.	private person, Machame	source: TROSS install: TROSS 1 Electra, 120 l with electric back-up
12.	Mollel company, Arusha	source: TROSS install: TROSS 2 Electra, 120 l with electric back-up; apparently out of order
13.	private person, Arusha	source: TROSS install: TROSS 2 Electra, 120 l with electric back-up
14.	Meru Meru secondary school, Moshi	source: TROSS install: TROSS 1 Electra, 120 l with electric back-up
15.	Kilimanjaro Christian Medical Centre, Infusion unit, Moshi	source: TROSS install: TROSS, 1994; funding: Lutheran mission, Arusha 6 panels Solatec, Kenya; 2 500l tanks with electric back-up
16.	Kilimanjaro Christian Medical Centre, Moshi, several wings	source: COST, own install: a.o. Total Solar Kenya, 1985; funding: several missions several systems in different wings; total ca. 100 m2; with el. back-up
17.	Kilimanjaro View Hotel, Moshi	source: TROSS instal: in progress, TROSS 23 panels, pumped circulation (Solatec, Kenya)
18.	'K' Keys hotel, Moshi	source: TROSS install: TROSS 1 MLU engineering (2 panels), 120 l with electric back-up out of order, badly installed
19.	private person, Usa River Arusha	source: TROSS install: TROSS 1 Electra, 120 l with electric back-up
20.	Duka Moja, Arusha	source: TROSS install: TROSS 1 Electra, 120 l with electric back-up
21.	Hoopoe safaris, Arusha Lake Manyara tented camp	source: own install: 1994/95Total Solar Kenya + self, after instruction 20 systems, 180 l, 2 panels, Total Solar work very satisfactory

22.	Serengeti Select Safaris Tarangire Safari Lodge	source: own install: 1988, self, bought from AISCO 10 MLU Engineering, 120 l with electric back-up (diesel generated electricity) electric elements and galvanized piping corroded after few years, but copper panels still work, despite little maintenance
23.	private person, Moshi	source: own Alpa Nguvu systems
24.	Lion Hotel P.O.Box 40051 Sinza BK "o", DSM Tel: 051-73808	source: own install: AISCO, 19884 imported systems from USA (MLU Engineering) with 4 isolated tanks (120 litre) with electric back-up heating; never functioned properly; problems: undersized, oriented to the east.
25.	University of Dar es Salaam Main campus	source: COST, own install: 1988, 2 units one imported system and one produced by the faculty of engineering; for research and demonstration purposes; in bad state.
26.	University of Dar es Salaam Dispensary	source: own 1 imported system; ± 2 m^2; apparently partly working, but far too small to meet demands of dispensary; glass plate badly covered with mud.
27.	Canadian embassy Dar es Salaam	source: own 2 systems
28.	ARDHI institute Dar es Salaam	source: own install: B&S international systems (2 m2, pumped?), directed to the east, tilt < 15
29.	USAID, Dar es Salaam	source, sales and installation: Wilken telecom, 1993/94 17 Solahart 180 litre systems for staff houses
30.	2 x private persons, Bahari beach, Dar es Salaam	source and sales: Nabikia Afrika; self-installation, 1995 2 Solco, 100 litre integrated, thermosyphon, stand-alone systems
31.	Selous Game Reserve Lodge	source & sales: Nabikia Afrika; self-installation, 1995 1 Solco, 100 litre integrated, thermosyphon, stand-alone system
32.	De Luxe Hotel Mwanza	source: own MLU engineering, USA, AISCO
33.	Bugando hospital Mwanza	source: Sawe, TIRDO, COST install: 1983, preheating water for hospital central heating 68 units, 680 m^2, 18900 kWh (replacing 2270 litres of industrial diesel oil a month);US$ 40,000, funded by West-Germany funded: TRC
34.	Min. of Agriculture Training Institute, Nyegezi, Mwanza	source: TIRDO, COST COST install: 1985, 340 m^3 (?) but not working TIRDO install: 1983, 340 m^2, stopped working in 1984, due to shortage of water pre-heating water for cooking purposes funds: ministry of agriculture

35.	Karibuni Centre, Mbeya	source: own install: self, bought through AISCO, 1989 2 MLU engineering systems, 120 l with el. backup; one out of order: air-locks & problems with water supply
36.	Milimani Hotel Njombe	source: own 6 x MLU Engineering systems, 120 l with el. backup
37.	Tea estate Tukuyu	source: own self-manufactured and installed, 1995 employees of tea estate participated in BACIBO-course 1995 220 l, 2,5m^2, serpentine, galvanised steel
38.	Mbeya referral hospital maternity wing, Mbeya	source: TIRDO, COST hot water for maternity wing funded: British Council
39.	Mwambani district hospital Mwajuni	source: BACIBO 1981, replacing wood fuel system; functions well; sheet absorber
40.	Turiani hospital, Makete Ndala hospital, Makete Ruanda Homecraft Centre	) source: BACIBO) parallel pipe absorber, 7 systems, 1 in disorder (lack of maintenance)) install: 1983
41.	Girls Secondary school Mbeya	source: BACIBO install: locally produced and installed under supervision of BACIBO, parallel pipe absorber; 1981/83
42.	Orphanage, Igogwe	source: BACIBO, own install: locally produced and installed under supervision of BACIBO, 1981/83
43.	Dispensary, Mbalizi Novicatte, Mtinko	) source: BACIBO) install: locally produced and installed under supervision of BACIBO, 1995
44.	Consolata Itonda hospital Itandala, Njombe	source: TIRDO funded: Tanzanian & Italian government
45.	Makiungu R.Catholic Hospital Singida	source: TIRDO, COST install: 1987, 9 units, 540 litres; also PV panels funded: Irish government + RC mission
46.	Manyoni R. Catholic mission Singida	source: TIRDO, COST COST: install 1978, 200 litres TIRDO: install 1978, 400 litres, 2 units; domestic use; problems with salt deposition, but in good working condition; funded: RC mission
47.	Iambi Hospital Singida	source: COST 60 litres

48.	Mkwawa High school Iringa	source: COST 1 unit
49.	Ikonda hospital, Makete, Iringa	source: COST
50.	Kristu Mfalme parish, Rukwa	source: COST
51.	Swedish school, Nzega	source: Jading several, imported from Sweden
52.	Nkinga hospital	source: Jading domestic use swedish missionaries
53.	Makumera theological college	source: own instal: early 1980's, funded by Lutheran mission, Arusha no longer working; recent attempts to rehabilitate
54.	Lutheran hospital, Singida	source: own instal: 1990, Solar World Kenya (?), funded Lutheran mission, Arusha apparently never worked; problems during implementation phase also PV installed in 1990: works satisfactory
55.	Passionist Community	source: own install: Wilken Telecommunications Kenya Solahart systems: indirect, electric back-up
56.	Wade Adams, building contractor	source: own instal: Wilken Telecommunications Kenya Solahart systems: indirect, electric back-up
57.	private person, Mbeya	source: BACIBO Alpa Nguvu systems
58.	Irente school for the blind, Tanga	source: own install: Alpa Nguvu, Kenya
59.	Mkonge hotel, bushtrekker chain Tanga	source: COST, own install: 1980 (?), AISCO; still operating
60. 61.	staff houses Chuo cha Kanisa, Morogoro	source: own both: 2 x 120 litre tank (MLU? with electric back-up) with 1 panel
62.	Salvatorian seminary, Morogoro	source: own; install: Coastal Steels ltd. 30 panels (2 m2), Ariston, Italy; indirect, pumped (controlled by differential thermostat); 3 hot water tanks with permanently pumped hot water circulation loops; problems with two circuits.
63.	Roman Catholic Mission Morogoro	source and sales: Intertec; self-installation 1995 3 Solahart 180 litre-sytems (indirect, thermosyphon, with el.back-up)
64.	Swiss Tropical Research Centre Fakara, Kilombero	source and sales: Intertec, self-installation, 1992/93 10 Solahart 180 litre systems (indirect, thermosyphon, el. back-up)

65.	Bishop Kisanji's Women Training Centre, Morogoro	source: COST install: 1979, 9 units
66.	Morogoro hotel, bushtrekker chain, Morogoro	source: COST install: 1988, AISCO, 120 litres systems (MLU Engineering/Electra)
67.	UNITAS RC, Bigwa Morogoro	source: COST 180 litres
68.	Dodoma Hotel Dodoma, opp. station tel: 061-20451	source: TIRDO install: 1987 hot water for rooms, laundry, kitchen 4 units, poor efficiency: technical problems
69.	Makoke Roman Catholic Church Musoma, Mara-region	source: TIRDO, COST COST: hospital + domestic use TIRDO: domestic use, funded: RC mission
70.	Karagwe Hospital Bukoba district	source: TIRDO, COST TIRDO: funded DANIDA + Lutheran church of Tanzania, 3 units
71.	Kashasha Village Techn. Training Centre, Kagera, Bukoba district	source: TIRDO, COST TIRDO: 1 unit, funded DANIDA
72.	Sikonge Hospital Tabora	source: TIRDO, COST TIRDO: 1 unit funded by DANIDA hot water for hospital theatre and laundry
73.	Saint Wailburg's hospital Nyangao, Lindi	source: TIRDO, COST TIRDO: domestic use, funded RC mission

Appendix III: Literature

- B. Andersson; Solar water heaters in developing countries; 1984.

- Bank of Tanzania; Economic Bulletin for the quarter ended 30th June 1995, Vol.24, No.2; Dar es Salaam, 1995

- L. Berry; Tanzania - physical and social geography; in: Africa South of the Sahara; pp. 884 - 905, 1994.

- A. van Braam; Leerboek bestuurskunde; Muiderberg, 1988.

- L.A. Brown; Innovation diffusion: a new perspective; London, 1981.

- J.C. Bruggink; The socio-economic aspects of introducing solar flat plate collector technology in the Sahel; ILO, Geneva, 1984;

- Bureau of Statistics; Bi-annual hotel statistics report; President's Office, Planning Commission, Dar es Salaam, March 1995.

- Bureau of Statistics; Environment statistics in Tanzania mainland; President's Office, Planning Commission, Dar es Salaam, 1994.

- V. Buskens; A theory about diffusion of innovations in developing countries - practical experiences in Tanzania; Eindhoven University of Technology, 1992.

- Confederation of Tanzanian Industries (CTI) - US Agency for International Development (USAID) Program; Industrial policy proposal; Dar es Salaam, 1994.

- J.-C. Debeir, J.-P. Deléage, D. Hémery; In the servitude of power - energy and civilization through the ages; London, 1991.

- B. Deuss; Zig Zag collector: manual on the construction of a solar water heater; TOOL/BACIBO, Amsterdam, 1987.

- W. Dickinson, P.N. Cheremisinoff; Solar energy technology handbook - part A: fundamentals; 1980.

- J.A. Duffie, W.A. Beckman; Solar engineering of thermal processes; New York, 1993.

- East African Meteorological Department; Climatological statistics for East Africa, part II: Tanzania; Nairobi, September 1975.

- The Economist Intelligence Unit (EIU); Country profile Kenya 1994-95; London 1995.

- The Economist Intelligence Unit (EIU); Country profile Tanzania 1994-95; London 1995.

- ESMAP; Energy efficiency activity in Tanzania: reports on walkthrough audits; TIRDO, AF Energikonsult AB, 1989.

- M.S. Gamser; Innovation, technical assistance and development: the importance of technology users; in: World Development, Vol. 16, No. 6, pp. 771-721, 1988.

- M.A. Hankins; Renewable energy in Kenya; Nairobi, 1987.

- M.A. Hankins, M. Bess; Photovoltaic power to the people - the Kenya case; World Bank, Washington D.C., 1994.

- J. Hardeman; Selectieve innovatie door kleine boeren in Mexico - Bijdragen tot de Sociale Geografie en Planologie nr. 8; Amsterdam, 1984.
- R. Hosier, W. Kipondya; Urban household energy use in Tanzania: prices, substitutes and poverty; in: Energy Policy, Vol.21, No. 5, May 1993, pp. 454 - 473.
- C.C. Hood; The tools of government; New Jersey, 1983.
- C. Hurst; Establishing new markets for mature energy equipment in developing countries: experience with windmills, hydro-powered mills and solar water heaters; in: World Development Vol.18, No.4, pp.605-615; 1990.
- International Organization for Standardization; Solar heating - domestic water heating systems - part 5: system performance by means of whole system testing and computer simulation; DRAFT; 1994
- G. Jacobs; Wind pumps in the Province of Iloilo, the Philippines - opportunities and constraints; Eindhoven University of Technology, 1992.
- Y. Jading, O. Jonsson; Solar water heating in Tanzania; MSc. thesis Institute of physical resource theory, Chalmers University of Technology, Goteborg, 1992.
- S. Karekesi, e.a.; Photovoltaics and solar water heaters in Kenya; Nairobi, 1994.
- Kenya Power & Lighting Company; personal contact: Mr. J. Ouma, commercial manager.
- M.J. Kimani, E. Naumann; Recent experiences in research, development and dissemination of renewable energy technologies in Sub-Saharan Africa; Nairobi, 1993.
- I. Maso; Kwalitatief onderzoek; Amsterdam, 1987.
- Ministry of Water Energy and Minerals; The energy policy of Tanzania; Dar es Salaam, 1992.
- G.L. Morrison, e.a.; Outdoor testing of solar water heaters - effects of load pattern and auxiliary boosting; in: Solar Energy, Vol.49, No.4, pp.299-308, 1992.
- M. Mwandosya, M. Luhanga; Energy and development in Tanzania: issues and perspectives; in: Energy Policy, Vol.21, No. 5, May 1993, pp. 441 - 452.
- N.C.X. Mwihava, A.Towo; A study and assessment of energy projects and their effective utilization in Tanzania; COSTECH, Dar es Salaam, 1994.
- OECD; managing technological change in less-advanced developing countries; Paris, 1991.
- G. Oelert, F. Auer, K. Pertz; Economic issues of renewable energy systems; GTZ, Eschborn, 1988.
- C. Rioba, H. Thomas; A survey of solar water heating systems available in Kenya; Bellerive Foundation; Nairobi, 1990.
- E.M. Rogers; Diffusion of innovations; New York, 1995 (EUR).
- M. Rommel, A. Wagner; Application of transparent insulation materials in improved flat-plate collectors and integrated collector storages; in: Solar Energy, Vol.49, No.5, pp.371-380, 1992.

- E. Sawe; Renewable energy policies in Tanzania; in: M.J. Mwandosya, M.L. Luhanga (eds): Proceedings of the seminar on national energy policy for Tanzania, Arusha, 10-14 September 1990; Stockholm Environment Institute, 1991.

- F. Salvesen; New and renewable sources of energy in Tanzania; Det Norske Veritas Industry AS, Hovik, 1994.

- G. Skartvedt; Solar water heating; in: J.F. Kreider, F. Kreith (eds.); Solar energy handbook; McGraw-Hill, 1981.

- J. Streib; Hot water from the sun - how to construct your own solar panel; Stuttgart, 1989.

- Tanesco; Electricity tariff study, Final report - Vol. 2; ODA, London, 1993.

- Tanzania/ESMAP; Electrical energy and demand survey of [various Tanzanian industries]; TIRDO, 1994.

- J. Tarimo; Experiences and potential for energy conservation in Tanzania; TIRDO, 1995.

- C.A. Velds; Zonnestraling in Nederland - klimaat van Nederland 3; KNMI, 1992.

- H. Visser, J. van der Linden, G.A.H. van Amerongen, S. Bijma; Description of the dutch outdoor (DST) method for domestic hot water systems; Delft, 1994.

- F. van der Vleuten; Financial assessment of small-scale energy options; ETC Consultants, Leusden (The Netherlands), 1995.

- F. van der Vleuten; Renewable energy technologies in Tanzania; Dar es Salaam,1995.

- D. Walubengo, M.J.Kimanu (eds.); The development and dissemination of renewable energy technologies in Sub-Saharan Africa; Nairobi, 1993.

Appendix IV: List of institutions/organisations and users visited

A. Kenya

A.1. Institutions

- Kenya Energy and Environment Organisation (KENGO)
  P.O.Box 48197 tel: 254.2.749747 / 748281
  Nairobi, Kenya fax: 254.2.749382
  telex: 25222

- African Policy Research Network (AFREPREN), Mr. Stanley Bii
  P.O.Box 30979 tel: 254.2.566032
  Nairobi, Kenya fax: 254.2.561464
  e-mail: stephen.karakezi@elci.gn.apc.org

- Energy Alternatives Africa Ltd., Mr. Mark A. Hankins
  Kileleshwa Gatundu Close tel: 254.2.565616
  P.O.Box 76406, Nairobi, Kenya fax: 254.2.729447
  e-mail: energy_africa@tt.sasa.unep.no

A.2. Demand

- Aeroclub
  Wilson Airport
  Nairobi, Kenya

- New Stanley Hotel, Mr. Mwaore, chief engineer
  Kenyatta avenue
  Nairobi, Kenya

A.3. Supply

- Wilken Telecommunications (Kenya) Ltd., Mrs. Etta B. Ligale, assistant marketing manager
  P.O.Box 49428 tel: 254.2.501506 / 7 / 8
  Nairobi, Kenya fax: 254.2.501754
  e-mail: telex: 22416

- Digitel communication systems Ltd., Mr. J.P. Savage, managing director
  Wilson Airport res: 254.2.884100
  P.O.Box 56366 tel: 254.2.504272
  Nairobi, Kenya fax: 254.2.604216

- Solar World, Mr. Charles Rioba, director;
  also teacher at Kenyatta University, department of Appropriate Technology
  P.O.Box 78516 tel: 254.2.784505
  Nairobi, Kenya res: 254.2.793471

- Kenital, Mr. Silvio Borracino, managing director
  head office: Argwings Kodhek road (next to Yaya centre)
  P.O.Box 55517 tel/fax:254.2.567579 / 562295 / 562583
  Nairobi, Kenya

- Solatec Ltd., Mr. Resham Bhangra, director
  Komorock rd, Dandora,
  P.O.Box 41103 tel: 254.2.793435 / 793295
  Nairobi, Kenya fax: 254.2.791878 / 532808

- Total Solar Kenya Ltd.; Mr. M. Wanjagi, sales engineer; Mr. J.Kinyanjui, sales representative
  Embakasi road,
  P.O.Box 18654 tel: 254.2.823411 - 6 / 823422
  Nairobi, Kenya fax: 254.2.823905 / 10

- Italproducts Ltd.: Mr. G.Vescovo, managing director
  P.O.Box 48952 tel: 254.2.556950
  Nairobi, Kenya

Other businesses in solar water heating in Kenya (not visited) include:

- Interlinks, Nairobi
- SOLCO Africa Ltd, Nairobi
- Botto Solar, Nakuru
- Solar Times, Nairobi

B. Tanzania

B.1. Institutions

- AGENDA: mr. Theo Tunga, editor tel: 051 - 38902
  c/o Business Care Services
  P.O. Box 71439 fax: 051 - 38910 / 46074
  Dar es Salaam, Olympio Street
  * Environmental NGO; also publish a monthly magazine on environmental issues

- Centre for Agricultural Mechanisation & Rural Technologies (CAMARTEC):
  mr. E.L.N. NG'wandu
  P.O.Box 764 tel: 057 - 3222 / 8250
  Arusha fax: 057 - 8250
  * Research organization; developed a solar water heater for local production in the 1980s; project was discontinued; transfer of the technology to local producers did succeed.

- Ministry of Finance, Customs department: mr. Fillan Saidi, head of statistics;
  mr. Tom Koko, head of Tariffs
  P.O.Box 9131 tel: 051 -24075
  Dar es Salaam, EAC Building

- Embassy of the Federal Republic of Germany: mr. R. Lerch, first secretary
  P.O. Box 9541 tel: 051 - 46334
  Dar es Salaam, NIC-building fax: 051 - 46292

- Foundation BACIBO: mr. & mrs. Bart & Cis Deuss
  Achterhoekseweg 11
  7556 BB Hengelo,The Netherlands
  * NGO supporting production of solar water eaters in developing countries

- Ministry of Communications and Works: Directorate General of Meteorology
  P.O.Box 3056 tel: 051 - 20881 / 26231
  Dar es Salaam, EAC-building telex: 41442 HEWA

- Ministry of Water, energy & Minerals: mr. B.J.Mrindoko: ass. commissioner renewables,
  mr. E.N.Sawe: principal executive engineer renewable energy; mr. H.A. Mbise,
  P.O.Box 2000 tel: 051 - 22002 / 31433
  Dar es Salaam, Sokoine drive / Mkwepu street fax: 051 - 37139/8 telex: 41777 maji

- Royal Danish Embassy, DANIDA: mr. Hildrup, coordinator health sector
  P.O.Box 9171 tel: 051 - 46318 / 23
  Dar es Salaam, Ghana Avenue fax: 051 - 46312 telex: 41057

- Royal Dutch Embassy:
  mr. B. Hensen, second secretary Environment, Small Enterprise Development
  P.O.Box 9534 tel: 051 - 46391 / 4
  Dar es Salaam, ATC-building fax: 051 - 46189

- Royal Norwegian Embassy, NORAD: mr. Alf Adler
  P.O.Box 2646 tel: 051 - 46815 / 46443 / 399952-5 / 35310
  Dar es Salaam, Mirambo Street / Garden Avenue

- Royal Swedish Embassy: mr. J. Furengren, program officer infrastructure
  P.O. Box 9274 tel: 051 - 46512/3 ; 23501/4
  Dar es Salaam, Extelcoms-building fax: 051 - 46928
  telex: 41013 SVENSK

- Tanzania Electric Supply Company (Tanesco):
  mr. M.J.J.Katyega, manager Demand Side Management Project
  P.O. Box 9024 tel: 051 - 27281-5
  Dar es Salaam fax: 051 - 36247 / 44668
  telex: 41318

- Tanzania Industrial Research and Development Organization: mr. J. Tarimo
  P.O.Box 23235 tel: 051 - 68822
  Dar es Salaam
  * Developed solar driers and are working on solar water heaters

- Tanzania Traditional Energy Development Organisation (TATEDO): mr. Meema
  P.O. Box 32974 tel: 051 - 74400
  Dar es Salaam fax: 051 - 46106
  * Sent a research proposal to Japanese donor organization JICA for a project on solar water heating

- University of Dar es Salaam,
  faculty of Mechanical Engineering: dr. G.John
  * courses and research projects on solar water heaters
  faculty of Physics: Dr. R.T. Kivaisi
  * research on selective paints
  P.O.Box 35131 tel: 051 - 43501
  Dar es Salaam fax: 051 - 43132

B.2. Demand

- Equator hotel
  P.O. Box 3002 tel: 057 - 3127
  Arusha
  * Installed solar water heaters in 1980s, but broke down; now using electricity to heat water

- Evangelical Lutheran Church Tanzania, Mr. Shadrack Kombe
  P.O.Box 3037 tel: 057 - 8855 / 6 / 7
  Arusha, Tanzania fax: 057 - 8858
  * Had several projects for missionary posts and Kilimanjaro Medical Centre done with solar water heaters

- Hoopoe safaris
  India street, P.O.Box 2047 tel: 057 - 7011
  Arusha, Tanzania fax: 057 - 8226
  * Have installed solar water heaters in their tented camp

- Hotel 77: mr. F.Nhwagi, chief maintenance engineer
  P.O.Box 7302 tel: 057 - 3800
  Arusha
  * Installed solar water heaters in the 1980s, still functioning, but some badly; lots of maintenance

- Hotel Karibu: mr. Jehangir, deputy general manager
  P.O. Box 20200 tel: 051 - 67760 / 67940 / 68458 / 68069
  Dar es Salaam, Haille Selassie Road fax: 051 - 68254 telex: 81038
  * using electricity to heat water; haven't considered using solar water heaters yet

- Impala hotel: Mr. Ole Mattasia, general manager
  P.O.Box 7302 tel: 057 - 2398 / 2962 / 7197 / 7394
  Arusha, Tanzania fax: 057 - 8220 / 8680
  * using electricity to heat water; generator electricity if grid fails; considering installation of large commercial system to save power costs

- Karibuni Centre: Suzanne Joos, manager
  P.O.Box 144 tel: 065 - 3035
  Mbeya
  * self-installed 2 systems in 1989 to save on electricity costs; one out of order: air-locks and problems with water supply

- Keys hotel: Mr. Sindato, manager
  P.O.Box 993
  Moshi, Tanzania tel: 055 - 52250
  * Had solar water heater installed in 1980s; broke down; now using electricity

- Kilimanjaro Christian Medical Centre
  Private bag tel: 055 - 54377
  Moshi, Tanzania
  * Several solar water heaters installed in different wings; some broken, some recently installed

- Kilimanjaro hotel: mr. Ole Saibul, chief engineer
  P.O. Box 9574 tel: 051 - 21281 - 9
  Dar es Salaam fax: 051 - 46762 telex: 41021
  * Using steam boiler system on IDO to heat water; might consider to buy solar water heaters for hot water for guest rooms once rehabilitation of hotel starts

- Lion Hotel
  P.O. Box 40051 tel: 051 - 73808
  Dar es Salaam
  * Had solar water heating system installed in 1980s; never functioned properly; no hot water at the moment; considering new solar water heaters.

- Mbalizi Evangelistic Church: mr. Joseph Jengwa
  P.O.Box 219 tel: 065 - 4232
  Mbeya
  * participated in BACIBO-course 1995; manufactured and installed 1 system

- New Arusha hotel: mr. J. Gerald, chief maintenance engineer
  P.O. Box 88 tel: 057 - 3241
  Arusha
  * Had large, commercial solar water heater system installed in the 1980s, but never functioned properly; now using fuel boilers

- Old Arusha Clinic, Dr. J.M. Urasha
  P.O.Box 89 tel: 057 - 2134
  Arusha, Tanzania
  * Recently installed solar water heater on clinic

- Palm Beach hotel: mr. Dimitri Ferentinos
  P.O.Box 1520 tel: 051 - 28891/3
  Dar es Salaam fax: 051 - 40203
  * Using electricity to heat water; high electricity bill; considered solar water heaters, but very high investment

- Salvatorian mission, Morogoro
  c/o Salvatorian Fathers & Brothers
  P.O. Box 2592 tel: 051 - 51040
  Dar es Salaam
  * Had large solar water heating installed to save on power costs

- Tarangire Safari Lodge, Mr. Stephen D. Simonson, general manager
  AICC, Ngorongoro wing, 2nd floor, P.O.Box 7182
  Arusha, Tanzania tel/fax: 255.57.7182
  * Installed solar water heaters at tented camp in 1980s

- University of Dar es Salaam, dispensary
  P.O.Box 35091 tel: 051 - 48132
  Dar es Salaam
  * Installed one solar water heater

- USAID: Dora Banawka-Hasan, head of procurement department
  P.O. Box 9130 Tel: 051 - 46429
  Dar es Salaam, ATC-building
  * Bought several solar water heaters recently to put on staff houses, because of power breaks and cost saving

B.3. Supply

- Agricultural Industrial Supplies Company Ltd. (AISCO)
  P.O.Box 4797tel: 051-25204
  Dar es Salaam, Upanga, Maktaba roadtelex: 42355 AGRIND
  * Parastatal, importing solar water heaters in 1980s; stopped this however.

- B&S International AS Tanzania: mr. Steen Lemmergaard - maintenance manager
  P.O.Box 5171tel: 051-35217fax: 051-35218
  Dar es Salaam; Pugu-roadtelex: 051-41256
  * Building contractor (Danish); installed and manufactured a few solar water heaters

- Biogas and Solar: mr. Ainea Kimaro, director
  P.O.Box 12446
  Arusha
  * Selling and building biogas plants; interested in local production of solar water heaters

- Bish international: mr. v.d. Winkelhof
  P.O.Box 1821tel: 68358res: 68822
  Dar es Salaam, kinondoni road
  * Building contractor (Dutch); installed solar water heaters in missions and hospitals

- BP Solar: mr. Raymond P. Mbilinyi, solar sales engineer
  P.O.Box 9043tel: 051 - 28900
  Dar es Salaamfax: 051- 46084telex: 41192 TZ
  * Selling and installing BP Solar photovoltaic solar systems; interested in promotion of solar energy in general: solar energy or industry association

- J.E. Elsworth Ltd.
  Docking, Kings Lynn
  Norfolk, PE31 8LY
  England
  * British engineer; interested in solar water heaters and local production with Tropical Solar Systems

- Energy Services Ltd.: mr. E.P. Msese - director / chief engineer
  P.O. Box 23145tel: 051 - 865930
  Dar es Salaam, Pugu Roadfax: 051 - 44283
  * Electrical contractors; interested in sales of solar water heaters and possibly local production

- Intertec Tanzania Ltd: mr. Seif Mwenguvu, head of solar department
  P.O.Box 40365 tel: 051 - 865280/1
  Dar es Salaam, Pugu Road fax: 051 - 865279
  * Electrical and mechanical contractors; importing solar water heaters from Australia (Solahart); interested in setting up Tanzanian Solar Energy Society

- Jandu Plumbers Ltd.: mr. M.S. Jandu, director
  P.O.Box 409 tel: 057-3468
  Arusha telex: 42093 JAPCOM
  * Electrical contractors and manufacturers; manufactured several solar water heaters locally in 1980s, but stopped, because not profitable; interested in importing solar water heaters

- Nabikia Africa Ltd: mr. Hamish Hamilton, managing director
  Private bag 138 — tel: 051 - 37633/4
  Dar es Salaam — fax: 051 - 44828
  * General trade company; importing solar water heaters form south Africa (SOLCO)

- Pembe Ranch Co.: mr. L. Horn, director
  P.O. Box 7094 — tel: 051 - 67916 / 67787
  Dar es Salaam, New Bagamoyo Road — fax: 051 - 67773
  * General trading company; starting import of solar water heaters from Greece (SOLE S.A., ALPHA)

- Solar Solutions: mr. J.M. Mantheakis, director
  P.O.Box 354 — tel&fax: 051- 44384
  Dar es Salaam, Konduchi — tel: 051 - 66174
  * Renewable energy company; staring import of solar water heaters from Greece (Helioakme, Megasun)

- Swift holdings: mr. Alex Rechsteiner
  P.O.Box 2082 — tel: 057 - 4147
  Arusha — fax: 057 - 8734
  * Solar PV company; interested in importing and installing solar water heaters

- Tropical Solar Systems, mr. Steve Kitutu, director
  P.O.Box 1746 — tel: 057 - 3506 / 3075
  Arusha, Tanzania — telex: 42064
  * Solar company; importing solar water heaters from Kenya (Solatec); interested in local production

- Wilken Telecommunications Ltd.: mr. Vincent Mboya, general manager
  P.O. Box 40781 — tel: 051 - 865617/8
  Dar es Salaam, Pugu road, Henkel Chemicals building — fax: 051 - 865618
  mobitel: 0811 - 324065
  telex: 41210
  * Telecommunications company; importing solar water heaters from Australia (Solahart)

Appendix V: List of industries studied and technologies for hot water production

Sources:
- ESMAP; Energy efficiency activity in Tanzania; reports on walkthrough audits; TIRDO, AF-Energikonsult AB, 1989;
- personal communication A.M. Kishebuka, Boiler Inspection, Labour Office, Dar es Salaam, 1995.
- Tanzania/ESMAP: Electrical energy and demand survey of 20 selected industries; TIRDO, Dar es Salaam, March - December 1994;
- J. Tarimo; Experiences and potential for energy conservation in Tanzania; TIRDO, 1995.

I Tanzania Breweries Ltd, Dar es Salaam
Steam boilers fired with Furnace Oil (FO);
ESMAP 1989 & 1994

II Friendship (Urafiki) Textile Mill Ltd.
Boilers on FO
ESMAP 1989 and 1994

III Tanganyika Dyeing & Weaving Mills Ltd (Sunguratex), Dar es Salaam
Boilers on FO
ESMAP, 1989

IV KIBO paper industries Ltd, KIBO paper mill Ltd.
Using FO for boilers
ESMAP, 1989

V KIOO Limited
Using FO for boilers
ESMAP, 1989

VI Aluminium Africa Ltd
No hot water boilers; using no significant amount of hot water
ESMAP 1989 and 1994

VII Ubungo Farm Implements Ltd.
No hot water boilers; using Industrial Diesel Oil (IDO) for other processes
ESMAP 1989 and 1994

VIII Tanzania Cigarette Co. Ltd.
Boiler using FO
ESMAP 1989 and 1994
note: according to Dr. J.Tarimo they installed a new boiler in 1994/95

IX Simba Plastics Co.
No significant hot water use; only uses electricity
ESMAP 1989

X Kisarawe Brick Factory Co. Ltd.
Using FO to heat boilers to pre-heat FO for furnaces
ESMAP 1989

XI Fahari Bottlers Ltd.
Using FO for steam boilers
ESMAP, 1994

XII Kilimanjaro hotel
Using IDO for steam boiler system, with heat exchangers for hot water cylinders
ESMAP 1994

XIII Tanzania & Italian Petroleum Refinery (TIPER)
boilers on FO to make steam for distillation
ESMAP 1994, Kishebuka, 1995

XIV General Tyre (E.A.) Ltd
No boilers, no significant hot water use
ESMAP 1994

XV Jigemee Sugar Factory Ltd, Zanzibar
Using hot water from boilers, unknown what fuel used
ESMAP 1994

XVI Steel Rolling Mills Ltd, Tanga
No boilers; no significant hot water use
ESMAP 1994

XVII Lower Ruvu Water Treatment Plant
No boilers; no significant hot water use
ESMAP 1994

XVIII Dar Brew (Kibuku), Dar es Salaam
boilers on FO
ESMAP 1994, Kishebuka 1995

XIX Tanzania Distilleries, Dar es Salaam
boilers on FO
Kishebuka 1995

Appendix VI: Cost estimation locally produced solar water heaters

BACIBO-design: galvanized steel snake absorber (ca. 2.5 m^2, no electric back-up)
estimated efficiency: 35%

	Materials	**Tshs**
-	3 x 6 m 0.5'' galvanized steel pipe	13,500
-	2 x galvanized steel sheet	20,000
-	glass sheet, ca. 3m^2	24,000
-	galvanized steel or hardwood for casing	30,000
-	nails, rubber, etc.	2,500
-	insulation material (glass wool, 5 cm)	8,000
-	1 tin of black board paint	8,000
-	6 tins of primer or red lead	42,000
-	tin solder and soldering flux	4,000
-	10 m flexible plastic hose and hose clips	7,500
-	elbows, sockets, T-pieces, couplings	10,150
-	storage tank (made of empty oil drum, insulated)	30,000
	subtotal	199,650
	contingency (10%)	19,965
	total material costs	**219615 Tshs** **= ca. 350 US$**

A.	material costs	350	US$
B.	production costs serpentine collector[3]	75	US$
C.	local transport, installation (piping, support, etc): 10%	42.5	US$
D.	profit: 10%	46.75	US$
E.	sales tax (30%)	154.28	US$
F	**Total**	**668.53** **= ca. 665** **= ca. 418950 Tshs**	**US$** **US$**

[3] production costs include labour and equipment costs; for a serpentine collector this is estimated at 75 US$, for a parallel pipe collector at 150 US$ due to the more difficult production (more welding or soldering, more use of soldering material). These estimates are loosely based on literature (Deuss, 1987; Streib, 1989).

Streib design: copper parallel pipe absorber (ca. 2.5 m^2, with electric back-up)
estimated efficiency: 45%

Materials		**Tshs**
-	copper pipe 0.5'' and 0.75''	27,000
-	2 x copper sheets	50,000
-	glass sheet, ca. $3m^2$	24,000
-	galvanized steel or hardwood for casing	30,000
-	nails, rubber, etc.	2,500
-	insulation material (glass wool, 5 cm)	8,000
-	1 tin of black board paint	8,000
-	6 tins of primer or red lead	42,000
-	welding rods and flux	8,000
-	copper pipe	12,000
-	elbows, sockets, T-pieces, couplings	24,100
-	storage tank (steel tank, insulated, electric heater)	110,000
	subtotal	313,600
	contingency (10%)	31,360
	total material costs	**344,960 Tshs** **= ca. 550 US$**

A.	material costs	550	US$
B.	production costs parallel pipe collector	150	US$
C.	local transport, installation (piping, support, etc): 10%	70	US$
D.	profit: 10%	77	US$
E.	sales tax (30%)	254,10	US$
F	**Total**	**1101,10**	**US$**
		= ca. 1100 US$	
		= ca. 694000 Tshs	

Appendix VII Questionnaires used and checklists used

Example questionnaire resource persons on solar water heating in Kenya

General information

Name		
Function		
Organisation/department		
Address		
Tel:	Fax:	Telex:

1. The use of hot water and solar water heaters

1.1. How many solar water heaters are used in Kenya (in numbers or m^2 panel area)? In what sectors? What is the hot water used for?

sector	main use of hot water	Amount in use	
urban household		none/some/many	No: ....
urban institutional		none/some/many	No: ....
industrial		none/some/many	No: ....
rural institutional		none/some/many	No: ....
other		none/some/many	No: ....

1.2. The main part of these systems, are they used stand-alone (only solar panels) or with a back-up energy source (electric or other)? Please tick first column and possibly specify.

	mainly stand-alone use
	mainly use with back-up: electric / other, namely: ....

1.3. What other energy technologies are used in these sectors to provide for hot water?

sector	electric heater	woodfuel boiler	other
urban house-hold	none/some/many	none/some/many	.... none/some/many
urban institutional	none/some/many	none/some/many	.... none/some/many
industrial	none/some/many	none/some/many	.... none/some/many
rural institutional	none/some/many	none/some/many	.... none/some/many
other	none/some/many	none/some/many	.... none/some/many

1.4. What factors - in your opinion - determine the choice to purchase a solar water heater or competing technology? In a positive or a negative way? Please tick first column and mark the last.

	Costs (on an annual basis)	positive/negative
	Investment	positive/negative
	Reliability	positive/negative
	Environmental concern	positive/negative
	Other:	positive/negative

1.5. What, in your opinion, are the main constraints for the <u>use</u> of solar water heaters in Kenya?

2. Manufacturing, installation and maintenance infrastructure

2.1. How many companies manufacture solar water heaters locally? What size are these companies?

size	no. of companies
small (<15 employees)	
medium	
large (>50 employees)	

2.2. How many companies are involved in import of systems? Where do these import their systems from?

Number of importers:
Countries of origin of systems:

2.3. Could you mention a few companies involved in manufacturing, import, installation and maintenance?

Company name	import/ manufacture	maintenance + installation	size: small/medium/large

2.4. What, in your opinion, are the main constraints for the **local production** of solar water heaters in Kenya?

3. Policy interventions

3.1. What did the government do to promote the **use** of solar water heaters? Please tick first column and possibly specify in the last column.

	laws / directives	
	subsidies / tax exemptions	
	installation on government property	
	awareness campaigns	
	other:...........................	

3.2. Did the government stimulate research and development of solar water heaters? What activities were supported? By what organisations?

name institution	**activity in solar water heating**

3.3. What efforts did the government make to stimulate the **local production** of solar water heaters in Kenya?

3.4. Did any other organisations particularly stimulate the development, dissemination and/or production of solar water heaters? In what way?

Name and type of organisation	activities

4. Miscellaneous

4.1. Are any publications available or has research been recently done on solar water heaters in Kenya (market studies, technology assessment studies, etc.)?

research / publication	author / organisation

4.2. Do you have any other suggestions or remarks about the use and production of solar water heaters in Kenya?

Data sheet for economic evaluation of solar water heaters in the household and institutional sector

General economic data

Real interest rate	:	(%)
Exchange rate	:	(US$/kshs)
General C.I.F. price	:	(% of F.O.B. price)
Import tax - PTA	:	(% of F.O.B. price)
- non-PTA	:	(% of F.O.B. price)

note: please indicate if import taxes are different for different kind of energy equipment

Irradiation data

yearly average radiation **Kenya**	:	($kWh/m^2.day$)
lowest mean monthly average	:	($kWh/m^2.day$)
in what month?	:	
yearly average radiation **Nairobi**	:	($kWh/m^2.day$)
lowest mean monthly average	:	($kWh/m^2.day$)
in what month?	:	

Fuel prices

Electricity	- households	:	(kshs/kWh)
	- institutions	:	(kshs/kWh)
Fuelwood	- urban	:	(kshs/kg)
	- rural	:	(kshs/kg)
Other, ...		:	(kshs/.....)

Equipment prices

equipment	price	size	installation costs
solar water heater (panels)	kshs	m^2	kshs
electric heater	kshs	kW	kshs
woodfuel boiler	kshs	litre	kshs
other:..................	kshs	......	kshs

<u>Thank you very much for your time and co-operation!!!</u>

Household water heating

Amount of hot water needed : (litres/day)
Cold water temperature : (^{0}C)
Hot water temperature : (^{0}C)

Local technology options

Technology	size	efficiency %	investment kshs	installation kshs	lifetime years	o&m costs %of investment
electric boiler	kW					
solar heater	m^2					
solar heater with el.back-up	panel: m^2 elect: kW		total:	total:		
other						

Imported technology options

Technology	size	efficiency %	investment kshs	installation kshs	lifetime years	o&m costs %of investment
electric boiler	kW					
solar heater	m^2					
solar heater with el.back-up	panel: m^2 elect: kW		total:	total:		
other						

Institutional water heating

Amount of hot water needed : (litres/day)
Cold water temperature : (^{0}C)
Hot water temperature : (^{0}C)

Local technology options

Technology	size	efficiency %	investment kshs	installation kshs	lifetime years	o&m costs %of investment
electric boiler	kW					
solar heater	m^2					
solar heater with el.back-up	panel: m^2 elect: kW		total:	total:		
other						

Imported technology options

Technology	size	efficiency %	investment kshs	installation kshs	lifetime years	o&m costs %of investment
electric boiler	kW					
solar heater	m^2					
solar heater with el.back-up	panel: m^2 elect: kW		total:	total:		
other						

Checklist interviews users

1. General information
Name:
Company name:
Function:
Age:
Address:
Telephone:
Male/female:
Name director: (male/female, age)

2. Organisational data

Type of organisation: hotel/hospital/other institution
Time in business?
Government/private:
Size
Access to credit?
Energy bill: electricity/woodfuel/other
Water bill:

3. Hot water use
How is water supplied?
Is there running hot water? How many hot water taps? Where?
What is the hot water used for? How much (litres per month)?
bathing/washing-up/laundry/cooking

What temperature	cold:	< 40°C
	warm:	40-70°C
	hot/boiling	> 70°C

Time of use?

4. Technology used
Is use made of solar water heaters?
What other technology is used or was used before?
Why was chosen (not) for solar water heater?
How and where did you get information on solar water heaters?
Advantages compared with alternatives?

Type of collector
Make: (manufacturer? catalogue available?)
Where bought: (import/local)
Size: m^2
Orientation: (north/east/south)
Tilt:
Efficiency:
Back-up heating?

5. Installation, maintenance and repair
Date:
Who :
Total investment costs:
Installation costs:
Expected lifetime:
Functioning?
Capacity tank (insulation material)
length of piping (insulation?)

Operation
Instruction/training?
Who operates?
Ease/control
Problems

Maintenance/repair
Who? When?
Cost?
Availability spare parts?
Breakdown? Maximum down-time?
Action in case of breakdown?
Acceptability cost/time?

6. Finance
Cost saving?
How investment capital?
Interest?

6. Constraints/opportunities
What are main constraints?
What do other people (customers/personnel/) think of using solar water heaters?
Would you buy solar water heaters again?
What if?

- cost price of solar water heater went down?
- maintenance cost went down?
- electricity/woodfuel price went up?
- obligation to install water heating equipment in effect?

Checklist interviews suppliers

1. General information
Name:
Company name:
Function:
Age:
Address:
Telephone:
Male/female:
Name director: (male/female, age)

2. Organisational data
Government/private:
Import/manufacturing:
Size of organisation:
Personnel?
Time in business?
Main business?

3. Import
Manufacturer systems?
Address
Telephone:
Contact with manufacturer: (delivery? spare parts?)
Type
Size
Efficiency
Import tariffs?
Customs?
Problems?

4. Manufacturing
Raw Materials: kind, price, quantity (per solar panel)
Source (import/local)
Quality (control)
Availability? Stock?

Personnel
No.? skilled/unskilled
Source for personnel?
Training?
Problems?

Machines and tools
Type?
Cost?
Source?
Operation and maintenance? Reliability?

Production organisation
Production planning
Subcontracting
Quality control
Information on designs? improvements? R&D

5. Technology
Type of solar water heater? auxiliary heating
Type of collector?
Size?
Water tanks and piping?
Other products

6. Installation
Site selection?
Design? System sizing?
Transport?
Personnel?
Costs

7. Operation and maintenance
Maintenance (contract, activities, frequency, records?)
Spare parts? (availability, exchangeability, organisation)
Mean time between failure?
Maximum downtime?
Communication?
Reference list of users?
Training for user operation and maintenance?

8. Demand: market segmentation and pricing
No. of panels manufactured/sold/installed per year?
Type of clients?
Promotion (money spent on marketing)?
Price setting?
Competition?

9. Finance
Source of finance (private/government/commercial)
Financial administration and planning
Turnover (min/normal/max)? profit?
Giving credit
How could the price of systems be reduced?

10. Institutional environment
Laws/licences
Taxes/subsidies
R&D, education, training?
Other help, (dis)incentives from institutions?

11. Possibilities/constraints
What are the main constraints?
What would the constraints be if the production (sales) doubled/tenfold?
What if?
- better design available
- reduced production cost
- easier/cheaper maintenance
- increased market/production

Help needed? (financial, materials, design, training personnel, other)?